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COSTS AND EFFECTIVENESS OF SELECTED ALTERNATIVE SECOND HOME WASTE DISPOSAL SYSTEMS APPLICABLE TO WEST TEXAX CONDITIONS

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August 24, 1976

Dr. Gordon D. Lewis
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240 West Prospect Street
Fort Collins, Colorado 80521

Re: Cooperative Agreement 16-348-CA

Dear Gordon:

I have enclosed one copy of the final report to the Eisenhower Consortium for Western Environmental Forestry Research under Cooperative Agreement No. 16-348-CA.

As indicated in our conversation on August 23, 1976, I will be attempting to publish material from this study in different outlets. However, if you should suggest some form of publication for the Eisenhower Consortium, I would be pleased to accommodate you.

Yours sincerely,

Kenneth B. Young

Dr. Kenneth B. Young

KBY:clw

COSTS AND EFFECTIVENESS OF SELECTED ALTERNATIVE SECOND HOME WASTE DISPOSAL SYSTEMS APPLICABLE TO WEST TEXAS CONDITIONS

by

Kenneth B. Young
Mesbah U. Ahmed

A Research Report to Eisenhower Consortium
For Western Environmental Forestry Research
Under Cooperative Agreement No. 16-348-CA

Department of Agricultural Economics
College of Agricultural Sciences
Texas Tech University

August 1976

SUMMARY

Inadequate treatment of wastewater from recreational areas is a major source of pollution in public waters. Many recreational areas are developed with individual disposal units for waste water treatment which subsequently become inadequate with continued population growth.

The impact of rising air and water quality standards together with mounting water demands to serve domestic, industrial and agricultural needs have provided a strong incentive to re-evaluate existing treatment systems and to promote more beneficial reuse of wastewater. Re-use of treated effluent can be expected to attain greater economic significance over time as conventional water supply sources become more restricted.

Land application of treated or semi-treated sewage effluent is a beneficial use that is attracting increasing interest. Additional information is needed on the economics of this practice for recreational areas and other small communities, and on associated treatment benefits of land disposal which may substitute for conventional treatment.

In this study, an intertemporal simulation model is developed to determine the least-cost decision rule with respect to the following four classes of waste water disposal decisions for a recreational area: (1) collection methods, (2) central treatment methods, (3) irrigation methods, and (4) selection of alternative irrigation sites and desirable negetation to be irrigated. Interactions among these disposal decisions are important features of the model. An application is made to a recreational area in West Texas located adjacent to a valuable municipal water supply lake.

Results of using alternative disposal methods are simulated from 1975 to 1995 to identify interactions between system components and to evaluate economics of the overall sewer project. Irrigation benefits are related to increased daily visitation and additional second home development at the study site. A major finding in the analysis is that additional permit sales generated at the lake site from irrigation development would offset at least a major part of system costs and that the proposed central sewage project would be economically feasible when compared with the alternative of individual septic tank installations.

ACKNOWLEDGMENTS

The following is a final report on a study financed by the Eisenhower Consortium for Western Environmental Forestry Research. A simulation model is developed to conjunctively evaluate alternative disposal methods for wastewater effluent at a second-home development. The model is applied to a recreational area in West Texas which has good potential for additional recreational development but which has the common problem of many relatively new development projects that the sewage treatment facilities are not adequate to support environmentally acceptable growth.

Contributions to this study were made by several other persons including Dr. Arun Walvekar of the Industrial Engineering Department at Texas Tech University, Mr. A. L. O'Brian, Manager of the White River Water District, Mr. Cecil Hawkes, Consulting Engineer of Lubbock, Mr. Dale Brown, Manager of Submatic Inc. of Lubbock and others. Appreciation is also due to Miss Sally Nesbitt and Miss Cathy Willingham for typing the manuscript.

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CHAPTER 1

INTRODUCTION

Inadequate treatment of sewage waste from a recreation area may result in serious pollution of streams and groundwater. In recreation areas, the common practice regarding sewage disposal is to use individual units such as septic tanks. The adequacy of treatment obtained with individual units varies with local soil conditions, intensity of rainfall, available disposal area, maintenance and other factors. Very often these individual units do not operate efficiently and the recreational lakes and groundwater become polluted by the wastewater discharges of lakeside residents. Some of the numerous recreational areas in the U.S. with potential pollution problems are: i) Grandview Lake, Columbus, Indiana (68); ii) Clifton Park, Country Knolls South, New York (22); iii) City of Saratoga Springs, New York (6); iv) Prince's Lake, Johnson County, Indiana (72); v) Phoenixville, Pennsylvania (6); vi) Cordry-Sweetwater Lakes, Brown County, Indiana (72).

The impact of rising air and water quality standards together with the mounting needs for water to serve domestic, industrial and agricultural requirements have initiated a search for alternative methods of treating and reusing wastewater for beneficial purposes. Reuse of effluent can be expected to attain greater economic value

over time as conventional sources of water supply become more restricted.

Environmentally acceptable and economical removal of polluting materials from sewage effluent is the primary goal of sewage treatment systems. Land application of treated or semitreated effluent, though not a new technology, has recently attracted increasing interest. Irrigation type facilities have been used under a wide variety of climate and soil conditions with various degrees of prior treatment of the applied wastewater. However, there appears to be a lack of definitive information on the parameters and constraints which have to be considered in the evaluation of cost effectiveness of a land application system. Very few researchers have attempted to analyze the economics and the efficiencies of conventional waste treatment means in conjunction with the complexities and advantages of a land application system.

A comparison of different types of sewage treatment, collection and effluent disposal techniques, within the constraints of interacting waste disposal standards, soil characteristics, and climatic factors is frequently needed by the planners of treatment facilities for recreation areas. Uses of treated or semitreated effluent may include irrigation of parks, golf courses, highway median strips, shade trees and forest lands. Although technical solutions to waste management problems either already exist or can be found without undue effort, answers are needed to many problems having their roots in social, economic, legal and political areas.

Purpose and Scope of the Study

The overall objective of the study is to develop and apply a system analysis model to conjunctively evaluate domestic sewage collection, treatment and disposal via alternative irrigation methods and uses at a recreation area.

A recreation area has unique operating characteristics because of varying population from season to season. Inadequate treatment of sewage from these sites may result in serious pollution of streams and groundwater. A further environmental factor is that a large number of lakes in arid and semiarid regions have relatively sparse vegetation. Development of a cleaner environment along with some shade trees and green campgrounds irrigated with sewage effluent would enhance the attractiveness of these sites. The feasibility of using effluent for irrigation depends on the interacting relationships among seasonal visitation, soil characteristics, climatic factors, comparative costs for treatment and irrigation, and types of vegetation to be grown within the constraints of waste disposal standards. The model developed in this study attempts to identify these interacting relationships.

Sewage treatment alternatives compared in this study are i) primary treatment plants, ii) stabilization ponds, iii) high rate trickling filter plants, iv) standard rate trickling filter plants, v) activated sludge plants, vi) extended aeration package plants and, vii) contact stabilization package plants and possible combinations of treatment alternatives. Individual septic tanks are not included

in this study as the costs and operating characteristics are available from other sources.

Alternative sewage collection systems evaluated in this study are conventional gravity flow system equipped with lift stations and a pressurized collection system composed of grinder pumps and booster pumps.

In conjunction with the above-mentioned collection and treatment alternatives, sprinkle irrigation of shade trees and grassed areas is compared with sub-irrigation methods. The analysis technique developed in this study is applied to White River Lake, Texas, as a case study of the costs and returns entailed in developing a more environmentally acceptable recreational area.

Organization of the Study

In order to inform readers of technical aspects of the system operation, the following major decision alternatives in sewage collection, treatment and effluent disposal systems at a recreation area are discussed in Chapter 2:

i) Sewage collection alternatives

ii) Central sewage treatment alternatives

iii) Alternative irrigation methods

Chapter 3 presents a review of previous studies pertaining to these decision alternatives and components of the system. The interacting relationships among the system variables are developed and a system analysis model is defined in Chapter 4. Chapter 5 illustrates

the use of the model for a specific site. Chapter 6 presents the findings of the model as applied to the case study area. A general evaluation of the model and its limitations for application in small community wastewater treatment-collection-disposal systems is presented in Chapter 7.

CHAPTER 2

REVIEW OF ALTERNATIVE METHODS FOR SEWAGE COLLECTION-TREATMENT AND DISPOSAL

The purpose of this chapter is to evaluate the sewage collection-treatment and effluent disposal alternatives available to a small community. The chronological order of the topics discussed in this chapter include: i) conventional gravity flow collection and pressurized conveyance systems, ii) primary treatment and various secondary treatments along with package treatment plants, and iii) sprinkler irrigation and sub-irrigation methods.

Collection Methods

Alternative facilities for conveyance of sewage are classified as i) conventional gravity flow method equipped with lift stations and manholes and ii) pressurized collection methods using grinder and booster pumps. With the conventional gravity method, the sewer pipes must have a continuous downward slope to assure gravity flow. There are limits on the depth of excavation along the sewer line to maintain the require slope, and pumping stations are used at intervals to lift up the sewage to the surface level. Manholes are provided to allow access to the sewers for inspection and cleaning.

Designing a sewer line to have a continuous downward slope requires at least several feet of excavation. This can be very

costly, especially where there is hilly terrain, rock, groundwater or unstable soil. A recent innovation in sewage collection systems is the use of grinder pumps and a low pressure conveyance method (53). The method can utilize smaller diameter pipe than conventional gravity flow systems and can overcome problems of land contours which are often encountered in recreation areas. With this method wastewater from households flows by gravity into a tank equipped with a grinder pump. When a predetermined amount of sewage is collected in the tank, the pump automatically starts operating, grinding up large particles of sewage and discharging it at pressure of 35 to 50 psi into a smaller diameter line. The discharge line from a grinder pump is normally 1-2/4 inches. The main is usually 2 inches diameter at the extreme ends of each branch and increases further in diameter as the load increases toward the final disposal point. As no gravity flow is entailed, this method is free from the rigorous constraints of grade and alignment. In hilly terrain, for example, the pressure sewer can be placed just below the surface following the contour of the ground. Another advantage of pressure sewers is the elimination of groundwater infiltration. The conventional gravity collection is subject to groundwater infiltration through loose-fitting joints and manholes. However, the relative economic feasibility of a gravity collection method or pressurized collection method entirely depends on the topography, concentration of development, and soil characteristics.

Treatment Alternatives

Contaminants in wastewater may be removed by physical, chemical and biological means. Selection of a sewage treatment alternative for potential irrigation use depends on the volume and characteristics of wastewater, regulations by local, state and federal agencies, and quality of treated effluent needed for irrigation.

The constituents of raw sewage influent and of subsequent treatment plant effluent depend upon quality of the municipal water supply and uses of water in the community. Although no specific conclusions can be drawn for a particular community by reference to generalized data, useful estimation of the likely treatment results can be developed from operating data of other established treatment facilities for a proposed treatment plant. Table 2.1 shows a comparison of sewage characteristics for selected types of development, whereas Table 2.2 shows average characteristics of untreated municipal sewage as reported by Metcalf and Eddy, Inc. (53).

Conventional wastewater treatment begins with preliminary operations such as screening and sedimentation (Figure 2.1). Effluent from these operations is identified as primary effluent. In the preliminary treatment, coarse screens first remove large floating objects and rags. Sedimentation removes 50-60 percent of the suspended solid matter. Approximately 25 to 40 percent BOD is removed by primary sedimentation.

Requirements for 80 to 90 percent removal of BOD and suspended solids can be met by conventional primary treatment. The primary

TABLE 2.1

COMPARISON OF SEWAGE CHARACTERISTICS FROM AREAS OF SELECTED TYPES OF DEVELOPMENT[a]

	Residential Areas				Industrial Areas	
Constituents	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2
Total solids mg/l	344	474	701	499	542	712
Suspended solids mg/l	120	117	283	56	199	81
Volatile solids mg/l	88	81	182	37.	125	63
Settleable solids mg/l	3.9	2.3	10.9	0.1	4.6	0.1
BOD mg/l	89	61	129	315	1002	198
COD mg/l	260	205	422	426	1689	367
Oil and grease mg/l	25	18	29	34	12	53
Coliforms $\frac{\text{MPN } 10^6}{100 \text{ ml}}$	84	79	52	297	653	150

[a]Source: Metcalf and Eddy Inc., "Wastewater Engineering: Collection, Treatment and Disposal," McGraw-Hill, 1972.

TABLE 2.2

UNTREATED MUNICIPAL WASTEWATER CHARACTERISTICS[a]

Constituent	mg/l (except as noted)		
	Strong	Medium	Weak
Physical			
Total solids	1200	700	350
Total suspended solids	350	200	100
Chemical			
Total dissolved solids	850	500	250
BOD	300	200	100
COD	1000	500	250
Total nitrogen	85	40	20
Ammonia nitrogen	50	25	12
Total phosphorous	20	10	6

[a]Source: Metcalf and Eddy Inc., "Wastewater Engineering: Collection, Treatment and Disposal," McGraw-Hill, 1972.

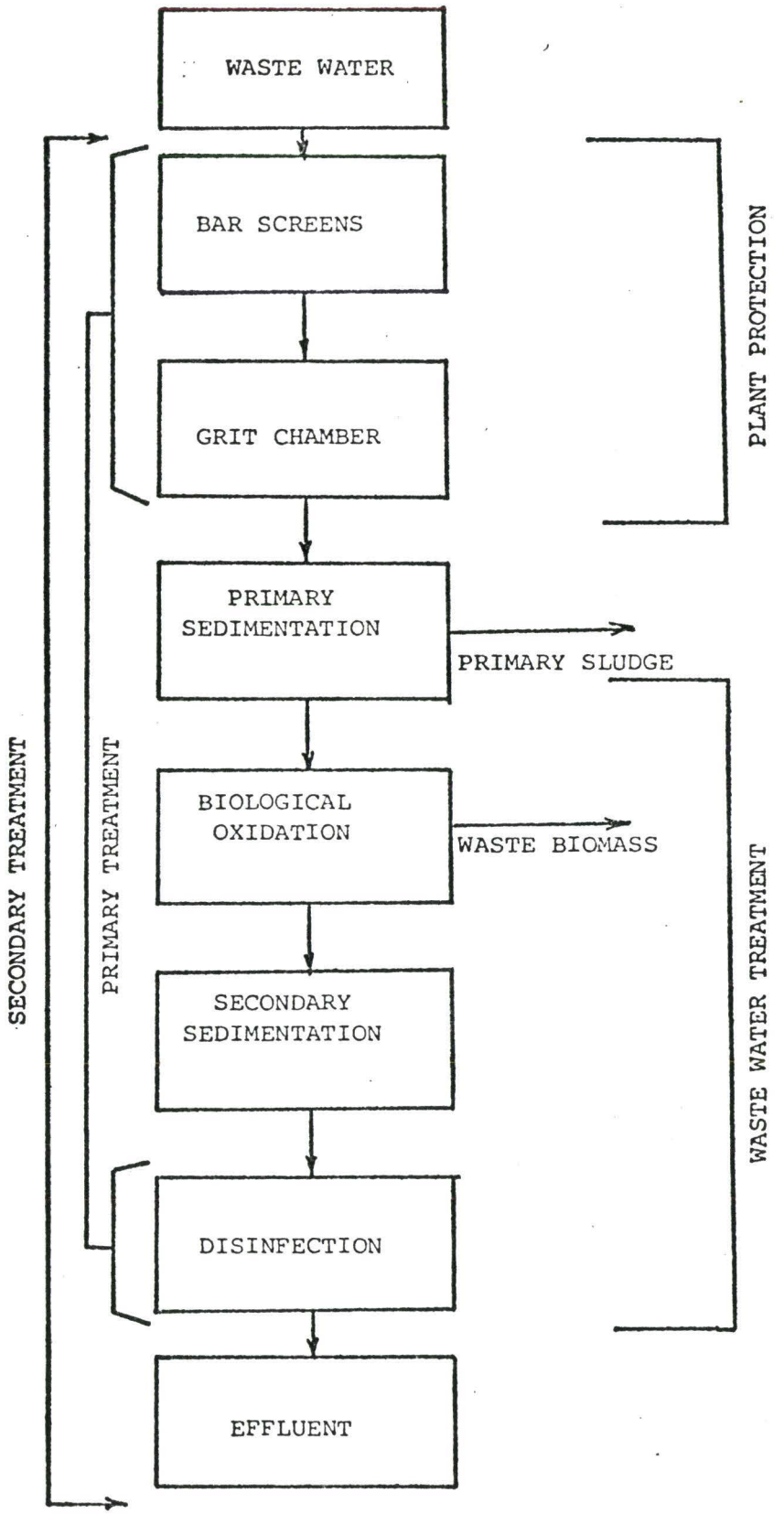

Figure 2.1 Flow diagram showing different stages of a conventional waste treatment plant.

effluent, therefore, may need to be further treated by biological processes. Effluent from biological processes such as activated sludge, trickling filters, or stabilization ponds is identified as secondary treated effluent. Biological processes are used to convert the finely divided and dissolved organic matter in wastewater into flocculent settleable solids that can be removed in the sedimentation tanks.

The use of package-type factory-assembled treatment plants has increased greatly in recent years for small communities. A package plant may be defined as a complex wastewater treatment plant designed, fabricated and assembled at a manufacturing location and transported to the treatment site where it is installed and connected to the wastewater influent and effluent pipes (47).

Efficiencies of different treatment plants for removal of contaminants vary considerably with characteristics of raw sewage. Table 2.3 shows typical characteristics of effluent from various types of treatment plants.

BOD removal and bacteria removal efficiencies of these treatment plants based on average performance and design criteria are shown in Table 2.4.

Methods of Application

There are a number of ways to apply wastewater to land. Each site may have different physical characteristics that influence the choice of application method. Typically, the irrigation method used for sewage treatment plant effluent has been sprinkle irrigation.

TABLE 2.3

AVERAGE EFFLUENT CHARACTERISTICS FROM VARIOUS TREATMENT PLANTS[a]

	mg/l			
		Secondary		
Constituent	Primary	Trickling filters	Activated sludge	Ponds
Total dissolved solids	1402	1166	917	1330
BOD	152	17	20	70
Total Nitrogen	37	16	23	23
Ammonia Nitrogen	23	5.9	17	8
Total phosphorous	11	13	12.9	6.7

[a]Source: Environmental Protection Agency, Waste Water Treatment and Reuse by Land Application. Vol. II, EPA - 660/2 - 73 - 006 b, Office of Research and Development, Washington, D.C. 20460.

TABLE 2.4

BOD AND BACTERIA REMOVAL EFFICIENCIES OF VARIOUS TREATMENT PLANTS BASED ON AVERAGE PERFORMANCE[a]

Treatment Process	BOD Removal %	Bacteria Removal %
Chlorination of commuted sewage (20 mg/l)	10	10-20
Primary Treatment (2 hr. settling; with chlorination; 20 mg/l)	35	25-75
High-rate trickling filter	76	80-95
Standard-rate trickling filter	88	90-95
Activated sludge	92	90-98
Stabilization Ponds	85	n/a
Primary + Stabilization Pond	80	n/a
Trickling filters + Stabilization Pond	95	n/a
Activated Sludge + Stabilization Pond	98	n/a
Extended Aeration or Contact Stabilization package plant	90	90-95

[a]Source: R. Frankel, "Water Quality Management and Engineering," An Unpublished Dissertation in Engineering, University of California, Berkely, 1965.

In the present study, sprinkle irrigation of shade trees and grassed lands is compared with sub-irrigation methods.

With the sprinkler irrigation methods, effluent is sprayed through nozzles above the ground surface. The rate of discharge can be varied by adjusting pressure nozzle and timing of application. The basic elements of a spray irrigation system are the pump, supply main, laterals, risers and sprinkler heads. The sprinkler system may be portable or permanent, moving or stationery. The effluent used in a spray disposal system must not contain solids that are large enough to plug the nozzles.

The principle behind drip or sub-irrigation methods is to achieve and maintain a relatively stable soil moisture condition. The normal strategy is to apply a small amount of water at frequent intervals so that the root zone is always maintained near field capacity and the plant is not exposed to stress. As a small area of the soil is wetted, evaporation losses are minimized and runoff and percolation losses are almost eliminated. The system can be installed either on the ground or below the surface. The underground trickle system offers a major advantage for safe effluent disposal since there is no direct human contact with effluent. These systems are easily automated and effluent flow can be regulated with a high degree of precision relative to plant consumptive use requirements. Figure 2.2 shows a typical layout for a drip irrigation system with its various components.

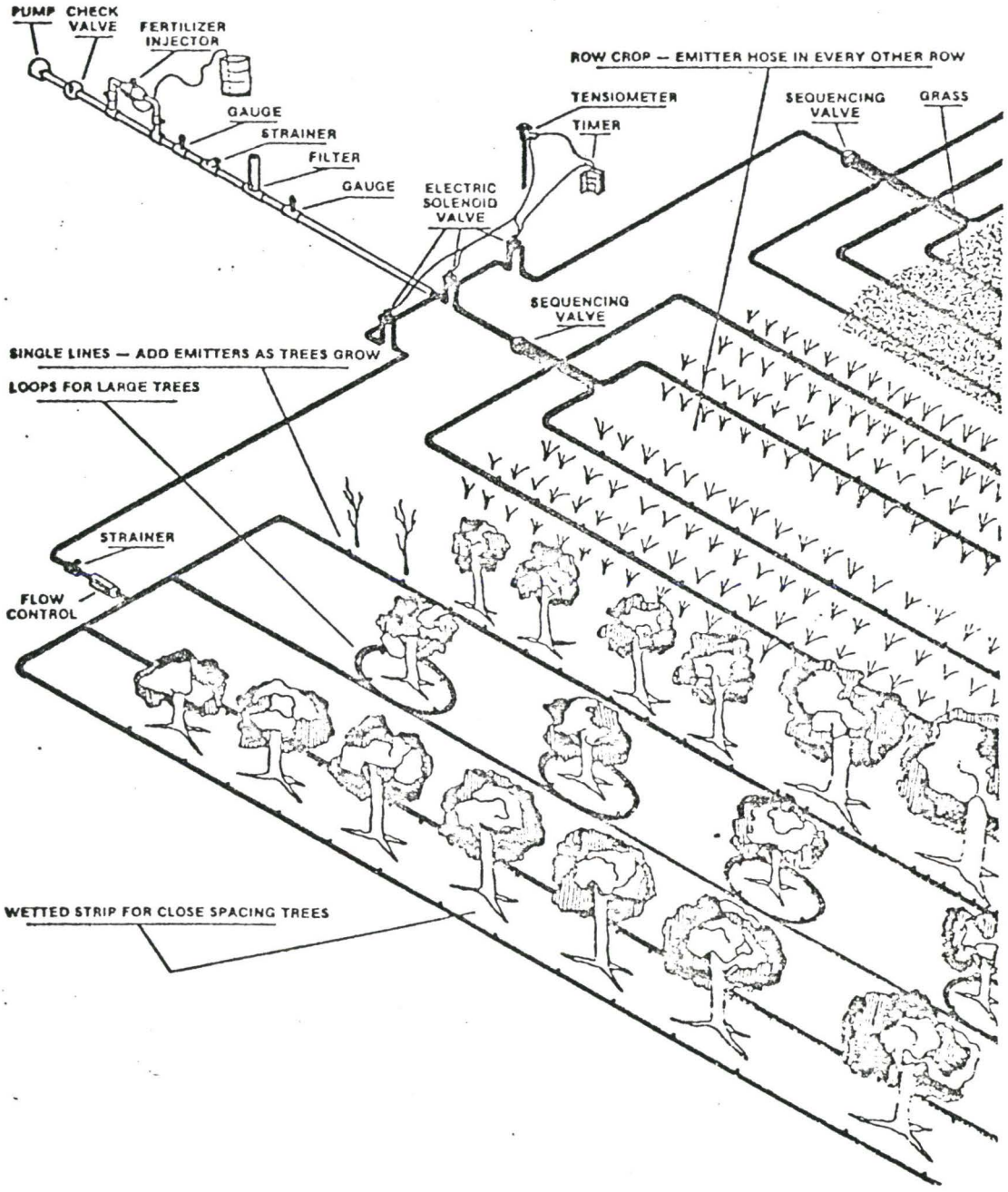

Figure 2.2. Layout of a drip system with various components.

The key to successful and uninterrupted operation of a drip system lies in keeping the emitters unclogged. The rate of flow from each emitter is about one-half to ten gallons per hour, and for such a slow rate, emitters have an orifice size from 1/10000th to 1/16th of an inch. Partial or complete clogging of emitters may damage plant growth as the amount of water applied in normal operation is regulated by consumptive use requirements.

The chief technical problem of sub-irrigation is emitter plugging by soil particles and algae. However, plugging may be controlled by extensive filtration and acid flushing of lines to eliminate algae buildup. Effluent of high salinity has been successfully used for four years to drip irrigate wine grapes in South Australia (67).

CHAPTER 3

LITERATURE SURVEY

Although a relatively large volume of literature is available on various wastewater treatment plants and on irrigation systems that utilize effluent, no specific studies appear to have been completed that employ a conjunctive systems analysis of sewage collection, treatment and disposal via irrigation systems. One notable exception is a relatively broad engineering-type study of wastewater treatment facility design and operation for three alternative disposal methods: irrigation, overland flow and infiltration-percolation recently completed by the Environmental Protection Agency (23). Current information on land applications of municipal and industrial wastewater is reported in this EPA study. The main purpose of the EPA study was to assemble detailed information on the engineering and design aspects of land application. However, it did not evaluate important economic interactions among various components of the system. Treatment plant selection and location may be affected by alternative beneficial uses for the effluent. Treatment requirements may also be affected by the method and location of effluent use, e.g., proximity of effluent use of a municipal water supply and irrigation application rates for vegetation in the disposal area.

In reviewing the literature, no previous research was located that evaluated domestic sewage collection, treatment and disposal by

alternative irrigation methods. Various studies have been reported on individual components of the system to be analyzed in this research work.

In developing a systems analysis model, it is necessary to further consider the technical and ecological feasibility of using sewage effluent for irrigation. An evaluation of methods for estimating and projecting visitation in a recreation area is included in the literature review as the volume of effluent is correlated with visitation. Also included in this chapter is a discussion of established methodologies for estimating the construction-operation and maintenance costs for various treatment plant alternatives. Some additional literature references on other components of the collection-irrigation-disposal system are discussed in developing the systems analysis model in Chapter 4.

Irrigation with Municipal Wastewater

During the past few years there has been a significant increase in the use of municipal wastewater for irrigation. Land disposal of wastewater dates back to prehistoric times, but recent environmental concerns have promoted greater interest in this practice.

Irrigation is the most common form of land application employed in the United States. A total of 367 communities used effluent for irrigation in 1964 (23). In 1972 there were 571 EPA land application facilities out of which 315 used some form of irrigation. Table 3.1 shows some operating data on land application systems at a few selected sites.

TABLE 3.1

DESIGN AND OPERATIONAL DATA ON LAND APPLICATION SYSTEM AT FEW SELECTED SITES

Sites	Type of Waste-water	Pre-treatment	Average Flow (mgd)	Method of Application	Soil Type	Crop	Irriga-tion Area (Acres)	Application rate (in/day)	Months used	BOD to Land mg/l
Abilene, Texas[a]	Municipal	Activated sludge, Effluent chlorina-tion	4.5	Border strip	Clay loam	Cotton Maize Grass	1550	6	5	17
Moulton-Niguel WD California[a]	Municipal	Activated sludge, Tertiary filtration, Effluent chlorina-tion.	0.5	Spray	Clay	Grass	160	1	7	30
Portales, New Mexico[a]	Municipal	Trickling filter	1.0	Spray, Ridge & Furrow Flooding	Sandy loam	Alfalfa Cotton Wheat	160	2	8	100
San Fran-cisco, California[a]	Municipal	Activated sludge, Effluent chlorina-tion	1.0	Spray	Sand	Grass	800	1	7	5-10

TABLE 3.1--Continued

Sites	Type of Waste-water	Pre-Treatment	Average Flow (mgd)	Method of Application	Soil Type	Crop	Irriga-tion Area (Acres)	Application rate (in/day)	Months used	BOD to Land mg/l
Woodland, California[a]	Municipal	Oxidation Pond	8.7	Flooding, Ridge & Furrow	Clay Loam	Milo	240	3	6	42
Lake George, New York[a]	Municipal	Trickling Filters	1.2 (summer) 0.3 (winter)	Spreading	Sand	N/A	N/A	8-10 (summer) 8 (winter)	12	30-46
Phoenix, Arizona[a]	Municipal	Activated Sludge	0.67	Spreading	Sandy Loam	N/A	N/A	24	12	10-20
Westby, Wisconsin[a]	Municipal	Trickling Filters	0.2	Ridge & Furrow	Silt Loam	Reed Canary Grass	6	1.2	12	33
Adelaide, Australia[b]	Municipal	Trickling Filters + Pond + Chlorination	21.9	Trickle	Sandy Loam & Clay	Vine-years	544	N/A	12	N/A
Lubbock, Texas[c]	Municipal	Imhoff tank + Pond	0.14	Spray	N/A	Pecan trees	60	N/A	N/A	N/A
R.F.B. Texas[d]	Municipal	Screen, Aeration, Chlorination & Pond	0.3	Spray	N/A	Grass	N/A	N/A	N/A	16

[a]Source: EPA, "Wastewater Treatment and Reuse," Vol. I and Vol. II, Office of Research and Developments. USEPA, Washington, D.C.

[b]Source: Read and Pietsch, "Australian Vineyard Uses Sewage Effluent with Trickle Irrigation," Proceedings: Second International Drip Irrigation Congress 74, San Diego, California, 1974.

[c]Source: Mr. Tom Scarborough, Tom's Tree Place, Lubbock, Texas.

[d]Source: Reese Air Force Base, Sewage Treatment Plant, Texas.

Treated municipal effluent was used for spray irrigation of croplands and forest stands for a ten-year period (1963-1972) in the Penn State Wastewater Renovation and Conservation Project (83). Crop yields and tree growth were significantly increased following the initiation of this project. In addition, the value of vegetation as a removing agent of damaging pollutants was demonstrated to be a vital part of the system. Types of crops irrigated with effluent in the project were wheat, oats, corn, alfalfa, red clover, and red canary grass. The forested area irrigated included a mixed hard wood forest, a red pine plantation and a sparse spruce plantation.

Younger et al. (114) reported preliminary results for an experiment at the Maloney Canyon Project (at San Bernadino National Forest). The objective of this project was to study the feasibility of using wastewater to irrigate green belts of native and introduced plants. The concept is that such green belts, if strategically placed, would reduce the wild fire hazard while disposing of wastewater and creating new recreation areas.

A study at the East-side Biofiltration plant at Ventura, California (84) demonstrated that use of effluent is not detrimental to grass growth on a proposed golf field. The study also showed that no harmful soil condition developed. Old Orchard, Seaside Bent, and Kentucky Blue Grass were the species irrigated. The report concludes that it is feasible to irrigate golf fields with effluent from secondary wastewater treatment plants which would ultimately

reduce dependency on the domestic water supply by about 520 million gallons per year in that region.

From a preliminary analysis of experimental data, Frost et al. (30) indicate that spray irrigation with pretreated stabilization pond effluent at Sunapee State Park in Newbury, New Hampshire does not result in any substantial or discernible alternation in composition of groundwater or downstream surface water. Most of the studies regarding the feasibility of using wastewater for irrigation have been concerned only with one irrigation method, namely "spary irrigation." On the other hand, trickle irrigation is a new method and is still in the developing stage. Very little research on the feasibility of using this method for effluent irrigation has been reported in the literature. Effluent water of high salinity was reported to be used for four years to drip irrigate wine grapes in South Australia (67). The treatment at this site includes conventional primary treatment followed by a high rate biofiltration and 345 hactares of stabilization lagoons. The effluent was moderately saline with an average total dissolved solids content of 1500 milligrams per litre and nitrate content of 2.9 - 89.0 milligrams per litre. The effluent from the stabilization pond was filtered with manually cleaned primary screen mesh filter at the pumping station and a secondary mesh filter located adjacent to the drippers. Algae growth in the pipeline and the emitters was controlled by periodic slug dosing with calcium hypochloride. Flocculated dead algae was removed from the pipelines by periodic flushing. After about four

years of operation, the soil salinity remained within acceptable limits. Plant growth and vigor were reported to be satisfactory despite high chloride levels in the leaves.

Although several research studies have been reported on the ecological feasibility of using effluent for irrigation, no studies appear to consider the various economic ramifications of this practice. From a conceptual viewpoint, there are significant economic interactions among irrigation alternatives, treatment plant selection, climate and soil characteristics, savings of potable water, and population of the locality within the constraints of effluent disposal standards. Technical and ecological feasibility of land application has been more or less well established. However, land application of sewage effluent has not been analyzed within the framework of a system economic model.

Visitation

Numerous studies have focused on the problems and methods of estimating demand for outdoor recreation and projecting future recreation visitation to a proposed reservoir. Ellis and Van Doren (21) noted that visitation for a given activity is associated with a spatial pattern from a complex interaction between people, facilities, resources and space. A simple method of projecting visitation, as used by Clawson and Knetsch (12), is a time series analysis of past visitation records to identify a trend of increase or decrease in visitations with time.

Some of the models which have been applied to predict attendance are the family of economic models, gravity and system theory models, and inertia models. The economic models, as initially developed by Pearse (60), assume that at a given "price" a certain number of visits are made to a given area. Under this assumption, a demand curve for different socioeconomic sectors of a specific population and different recreation areas and/or activities at different "price" may be formulated.

A number of gravity models, as described by Crevo (14) Ullman and Volk (99), Ullman (98), and Van Doren (101) are formulated on the assumption that the number of trips from an origin to a particular recreation destination is a function of the population as well as of the distance between two points. The following expression for the pairwise interaction between population and distance was used by Van Doren (101):

$$V_{i,j} = G \frac{P_i A_j}{TD_{ij} b} \qquad [3.1]$$

where $V_{i,j}$ = number of trips; G = the gravitational constant; P_i = population of origin; A_j = attraction index of destination j; $TD_{i,j}$ = minimum time distance on route ij and b = exponent.

As indicated in the above expression, Van Doren incorporated an attraction index to attempt to quantify the relative attractiveness of different sites. According to Wolfe (112), the gravity model is not responsive to the effect of distance. He found that the

number of short trips tended to be overestimated and longer ones were underestimated in a gravity model. Wolfe, therefore, developed the inertia model in order to incorporate the inertia element as follows:

$$V_{i,j} = \frac{P_i^p C_j^c}{D_{i,j}^d} \qquad D_{i,j} \frac{\text{Log} \frac{D_{i,j}}{m}}{n} \qquad [3.2]$$

where $V_{i,j}$ = number of recreational trips between city of origin i and resort of destination j; P_i = population or origin i; C_j = capacity of resort of ultimate destination (excluding resorts visited en route); $D_{i,j}$ = distance between city i and resort j; K, p, c, d, m and n are empirically developed parameters.

One of the most common difficulties in using gravity, inertia or economic models is that sufficient data are needed to estimate the empirical parameters for a specific recreation project. A relatively simpler method is to use the "Similar Project Approach." This method involves an application of the economic model using the per capita use curves for a similar project. The demand curves for 52 reservoirs in seven corps of engineers districts, estimated by using on-site survey data, appear in Technical Report No. 2, Estimating Initial Reservoir Recreation Use (94). These curves may be used to estimate future visitation for a proposed reservoir. It is assumed with this method that recreation sites located in similar demographic regions with similar natural and physical characteristics would generally experience similar use. The selection and adjustments of previously estimated per capita use curves to be adapted for the

engineers utilized to breaking down field costs into detailed components. A similar approach of using consulting engineering cost figures of units operations to break down entire plant field costs was also utilized by Frankel (28).

Michel (56) used the examples of federal grant assisted municipal wastewater plants that were audited from January 1965 to July 1968 to analyze the component costs of maintenance and operation for different types of treatment plants.

A more comprehensive technique for estimating the unit construction cost of municipal wastewater treatment plants both in terms of PE and design flow have been developed by Shah and Reid (79). Regional differences were considered in analyzing the data, and all relevant variables which were thought to affect cost were evaluated. Two methods were used to develop the cost estimate equations: i) analyzing separately the data for each type of plant, and ii) combining the data and using dummy variables to quantify the type of treatment plant.

A number of recent cost studies have dealt with package plants. Package plants were first introduced about 15 years ago to treat sewage from small communities. Detailed information on package plants including manufacturers, process alternatives, size and cost is available in the literature (47). Qusim et al. (64) conducted cost effectiveness studies of plants suitable for serving 500 to 1000 men in the U.S. Navy. Various technical data on plant size, volume, weight, fuel requirements, labor requirements and capital

cost are presented in Quasim's study. Seymore (74) has described the operational and performance characteristics of package treatment plants in the metropolitan sewer district of greater Cincinnati. Lamp (47) developed a more comprehensive cost analysis of package plants and considered different types of treatment available in package plants. The analyses were performed in terms of list price versus design capacity for various combinations of four variables: i) type of treatment, ii) type of sludge collection and return system, iii) type of basin material, and iv) presence and absence of a digester.

Most of the methods described above were considered in the present study in deriving a dependable cost estimate figure for different types of treatment plants. In a few instances, cost estimates for a specific treatment plant by various methods were found to vary widely. The methodology to handle these situations along with other cost estimate aspects of the present research are discussed more explicitly in the subsequent chapter while describing the analytical model.

Septic tank installations were not included in the analysis for the present study as an alternative to central treatment except for making cost comparisons. A recent Kansas study (35) indicated that septic tank systems are not cheap with a current construction cost of $1200 to $1500, an annual maintenance cost of $100 to $200, and an average lateral field life of only five to eight years. This translates to a monthly sewer charge per installation of approximately $30.

CHAPTER 4

THE SYSTEM MODEL

The purpose of this chapter is to identify the functional relationship among various components of a wastewater collection-treatment-disposal system and to develop a system simulation model of sufficient generality so that it can be applied at any recreational area. A schematic diagram of the system is shown in Figure 4.1. The model developed in this chapter attempts to formulate a digital analogy of the sewage collection-treatment-disposal system in order to "imitate" its real behavior using a digital computer. Various components of the model identified in Figure 4.1 are defined in the following discussion.

Visitation

This part of the model estimates daily visitation to various recreational facilities located at a recreational site. Estimation of visitation at different recreation facilities of the site is needed to evaluate revenue from visitor permit sales for recreational facilities and to estimate the volume of sewage to be treated. Factors affecting visitation to a recreation area are i) season, ii) climatic conditions, iii) sizes and socio-economic structures of nearby population centers, iv) distances of the population centers from the site, v) costs of using recreational facilities, vi) influences of other recreational areas, and vii) visual attractiveness

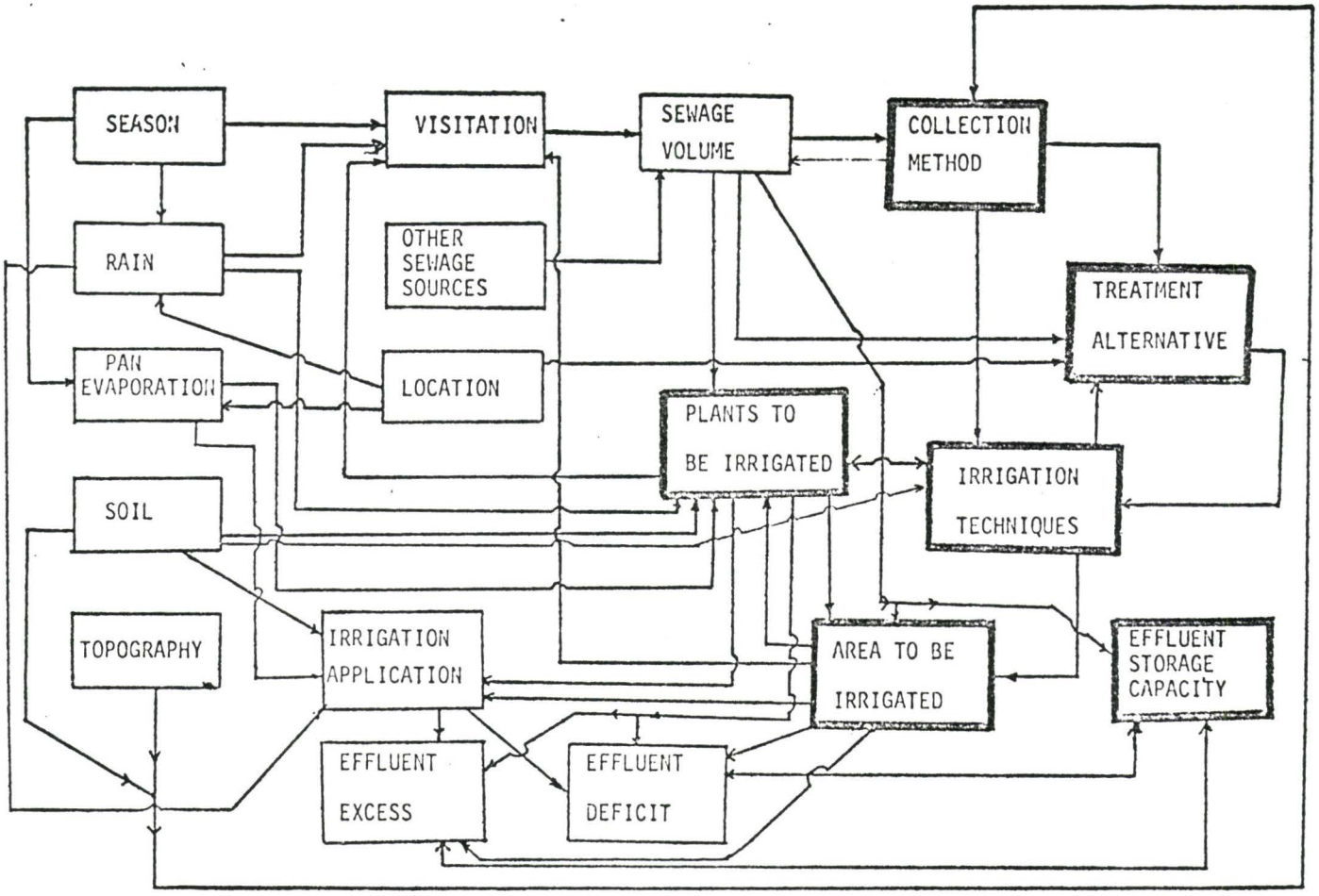

Figure 4.1. Schematic diagram of the system.

of the site. However, formulation of any model incorporating all of these variables in estimating daily visitation is complex, and would require sufficient relevant data.

The methodology employed in this study is to estimate daily visitation as schematically presented in Figure 4.2.

If the relevant data are available, annual visitation at the site may be estimated by using appropriate economic, gravity or inertia models as described in Chapter 3. Adequate treatment of seware to maintain a cleaner environment and to irrigate vegetation with effluence in semi-arid recreation areas would increase the attractiveness of the site. Most of the economic, gravity or inertia models used for predicting visitation incorporate some subjective measure of attractiveness.

A more simple method of estimating annual visitation is to assume that the records of previous visitations at the site, if available, implicitly reflect a trend of increase or decrease in annual visitation with time. With this method annual visitation, without considering the increasing attractiveness of the site, may be estimated by regression analysis of past visitation data against time. Mathematically, the simple underlying assumption is

$$\bar{A}_t = f(t) \qquad [4.3]$$

where $\bar{A}_t$, visitation in year t, is a function of year t.

An alternative method of estimating annual visitation without considering the increasing attractiveness of the site is to use the

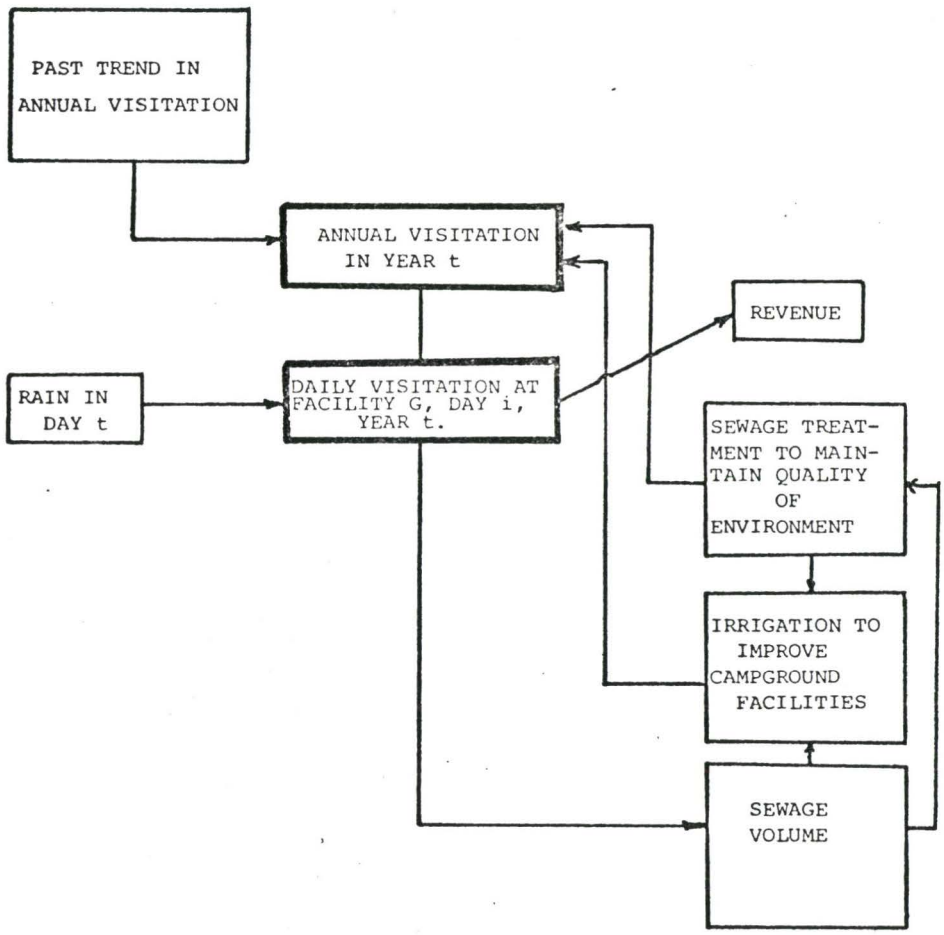
PAST TREND IN ANNUAL VISITATION
ANNUAL VISITATION IN YEAR t
REVENUE
RAIN IN DAY t
DAILY VISITATION AT FACILITY G, DAY i, YEAR t.
SEWAGE TREATMENT TO MAINTAIN QUALITY OF ENVIRONMENT
IRRIGATION TO IMPROVE CAMPGROUND FACILITIES
SEWAGE VOLUME

Figure 4.2. Schematic presentation of submodel "Visitation."

"Similar Project Approach." This method was discussed in Chapter 3. However, if annual visitation at the site is predicted by using any method which does not incorporate the attractiveness index (as in the case of regression analysis of past visitation records or by the "Similar Project Approach"), the estimated annual visitation needs to be modified as follows:

$$A_t^{o,p} = \nu_{o,p} \bar{A}_t \qquad [4.4]$$

where $\bar{V}_t$ = annual estimated visitation obtained without considering the influence of increasing attractiveness due to adequate sewage treatment and growth of vegetation. $\nu_{o,p}$ = attractiveness coefficient for increase in visitation due to sewage treatment alternative O and selection of irrigated plant species for alternative soil sites hereafter denoted as vegetation strategy, p.

The attractiveness coefficient, $\nu_{o,p}$ is difficult to quantify due to lack of sufficient relevant data. Subjective judgment is usually employed to quantify the attractiveness in almost all visitation models that have been used in the past.

Once the annual visitation is estimated, daily visitation at various recreational facilities is estimated as follows:

$$V_{q,i,t}^{o,p} = \bar{V}_{q,i,t}^{o,p} + [A_t^{o,p} - \sum_{i=1}^{365} \bar{V}_{q,i,t}^{o,p}] \frac{b_{q,i}}{(ND)_t} \times 365 \qquad [4.5]$$

where,

$$\bar{V}_{q,i,t}^{o,p} = \rho_i b_{q,i} A_t^{o,p} \qquad [4.6]$$

$$\rho_i = 1.0 \text{ if } R_1 \leq r_i$$

$$= \frac{R_i - r_2}{r_1 - r_2} \quad \text{if} \quad r_1 \leq R_i \leq r_2 \qquad [4.7]$$

$$= 0 \qquad \text{if } R_i > r_2$$

$$\text{and} \quad \sum_{q=1}^{n_q} \sum_{i=1}^{365} b_{q,i} = 1.0 \qquad [4.8]$$

In the above set of relationships

$V^{o,p}_{q,i,t}$ = Number of visitors at recreation Facility q, on day i of year t, corresponding to treatment alternative o and vegetation strategy p;

ρ_i = Rain coefficient for day i, representing the effects of rain on daily visitation;

$b_{q,i}$ = Daily visitation coefficients representing the fraction of annual visitation $A^{o,p}_t$ using at Facility q on day i;

n_q = Total number of recreation facilities available, such as campgrounds, trailor parking area, etc.;

r_i = Maximum amount of daily rain below which the usual daily visitation is not affected by rain;

r_2 = Minimum amount of rain above which visitation is nill; and

R_i = Rain on day i.

$(ND)_t$ = Number of days in year t with visitation greater than zero.

Daily visitation coefficients, $b_{q,i}$, can be estimated from the analysis of past records of daily visitation at various facilities and corresponding annual visitation. In case these data are not available, the monthly and weekend-weekday visitation data at different facilities in various recreation sites in U.S.A., such as collected by the U.S. Army Corps of Engineers (93) may be compared and adjusted to obtain reasonable estimates for $b_{q,i}$. Equation [4.7] implies that reductions in daily visitation due to rain are a linear function of rain if daily rainfall is within the range of $r_1 \leq R_i \leq r_2$. Visitation at the site on day i is assumed to be zero if rain exceeds r_2 on day i, and is assumed to remain unaffected if rain is less than r_1. In real life the relationship between daily rain and daily visitation may not be as simple as expressed in Equation [4.7]. Moreover, there are other important weather factors such as wind, temperature and duststorms that affect the daily visitation, but sufficient experimental data may not be available to integrate all of the factors in order to determine their effects on visitation. Definitive information on the functional relationships between rain and visitation was not available for this study. However, the model attempts to consider the effects of rain on visitation because, i) it is obvious that heavy daily rainfall reduces visitation, and ii) daily rainfall is a major climatic variable directly affecting the performance of other components of the system which have direct or indirect interactions with daily visitation. Examples of related components are irrigation requirements and the amount of infiltration into gravity collection

sewers due to heavy rain. Values of r_1 and r_2 are difficult to identify without past daily visitation-rain records or without experimental data. If these are not available, the values have to be assumed entirely on the basis of subjective judgments.

In short, the submodel for visitation works as follows:

i) annual visitation at the site is estimated.

ii) annual visitation is adjusted by assuming an increased attractiveness.

iii) the $b_{q,i}$ matrix is used to determine the number of daily visitors using different recreational facilities on day i.

iv) daily rain is generated in the submodel "Rain," (to be discussed later).

v) daily visitation at each facility is then adjusted to incorporate the effect of rain on day i.

In short, this component of the model estimates the number of daily visitors at various recreational facilities of a recreation area. The number of visitors at each recreation facility of the recreation area needs to be estimated because per capita sewage volume and per capita revenue from selling the recreation permits vary from facility to facility.

Once the daily visitations are computed, the model attempts to determine the daily volume of sewage as described in the next section.

Sewage Volume

For a small community, it is common practice to determine average sewer flows from population density and per capita contribution

of sewage. For large residential areas, flow rates are often determined on the basis of land area. Whenever possible, these flowrates are usually based on actual flow statistics from selected typical residential areas. In the absence of such data, an estimate of 70 percent of domestic water consumption may be used (53).

As mentioned previously, both visitation and per capita sewage flows vary for different recreation facilities. No specific past research work was obtained for this study to provide a definite procedure for estimating daily volume of sewage at a recreational area.

The procedure developed in this study for estimating daily wastewater flow in a recreation area, as shown in Figure 4.3 to evaluate visitation and per capita sewage flows by recreation use categories.

Sources of sewage in a recreation area may be classified into three major categories: First, facilities like campgrounds, visitor centers, trailer parking areas or the vacation homes tend to produce a variable amount of sewage depending upon visitations at these facilities. Second, sources like employee apartments, office buildings, and water treatment plants account for a relatively stable component of wastewater flow over a period. Third, the infiltration of groundwater or rainwater into sewers can be a major source of flow. The predicted flow is defined as:

$$S^{o,p}_{i,t,c} = \sum_{q=1}^{n^q} P_q \, V_{q,i,t} + \sum_{s=1}^{n^s} U_s \, N_s + T_{i,c} \qquad [4.9]$$

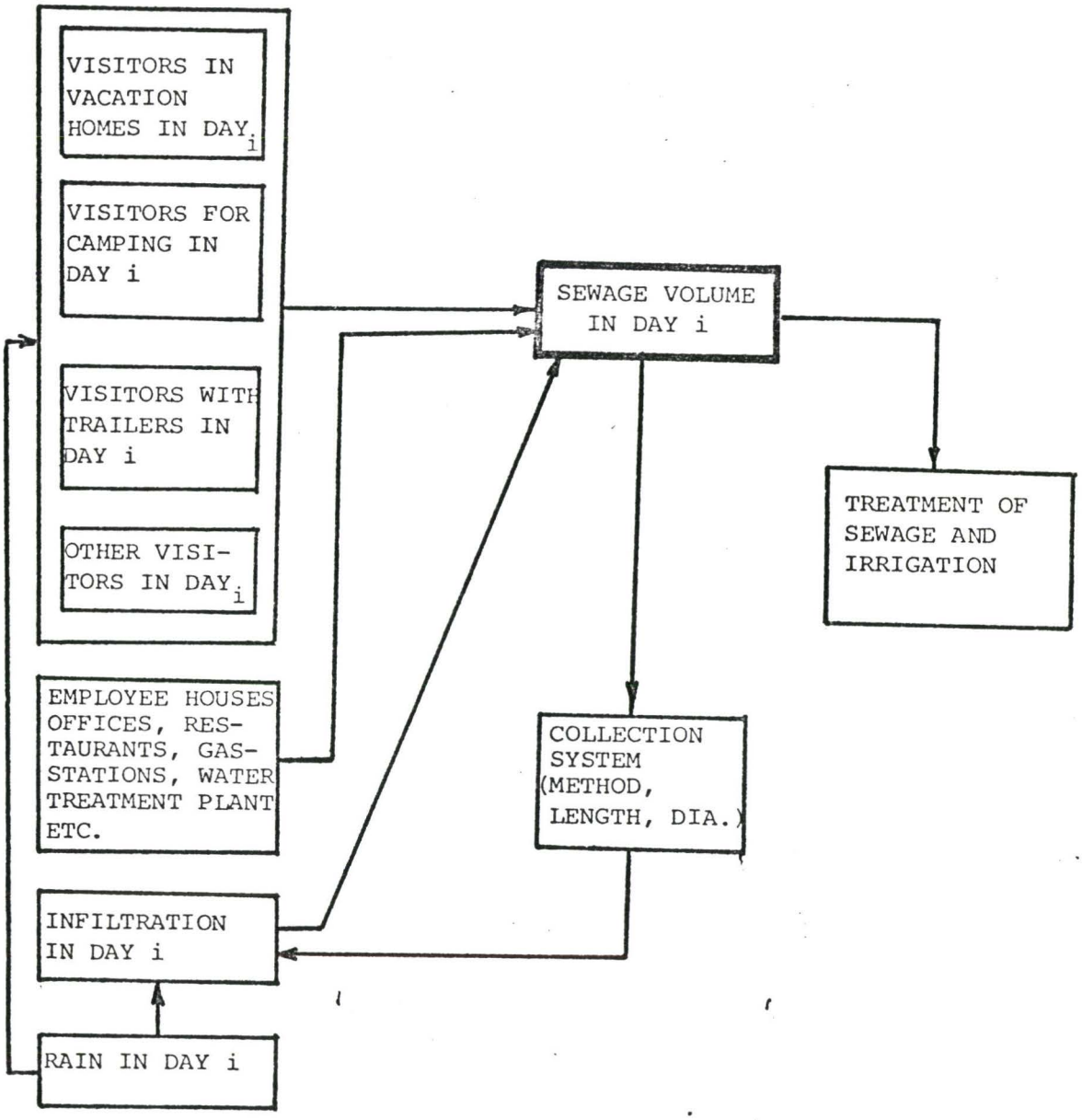
VISITORS IN VACATION HOMES IN DAY$_i$
VISITORS FOR CAMPING IN DAY i
VISITORS WITH TRAILERS IN DAY i
OTHER VISITORS IN DAY$_i$
SEWAGE VOLUME IN DAY i
TREATMENT OF SEWAGE AND IRRIGATION
EMPLOYEE HOUSES OFFICES, RESTAURANTS, GASSTATIONS, WATER TREATMENT PLANT ETC.
COLLECTION SYSTEM (METHOD, LENGTH, DIA.)
INFILTRATION IN DAY i
RAIN IN DAY i

Figure 4.3. Schematic presentation of submodel "Sewage Volume."

where, $S^{o,p}_{i,t.c}$ = Predicted volume of sewage on day i, year t with collection alternative c, where o and p have the usual notation defined previously.

P_q = Per capita sewage volume at facility q.

U_s = Volume of sewage per unit of s'th source in category B

N_s = Number of units of s'th sewage source in category B

n_s = Number of sewage sources in category B

$T_{i,c}$ = Infiltration of rain and groundwater into the collection system c.

Per capita sewage volume data (P_q) for different recreational use categories may be based on actual flow data from selected typical recreational areas. A complete listing of facilities and design flows from Yellowstone National Park, as reported by Metcaff and Eddy, Inc. (53) is presented in Table 4.1. Suggestions from consultant engineers or manufacturers of wastewater treatment facilities may also be used to estimate P_q values.

The presence of high groundwater tables results in leakage into the sewers and in an increase in the quantity of sewage. This infiltration may often range from 1000 to 40,000 gpd per mile of sewer (53). During heavy rains, when there is leakage through manhole covers as well as infiltration through sewers themselves, the rate may exceed 100,000 gpd per mile of sewers.

The extent of infiltration into the collection system is difficult to estimate due to its interacting relationships with soil characteristics, maintenance practice, materials and workmanship in

TABLE 4.1

DESIGN UNIT SEWAGE FLOWS FOR RECREATIONAL FACILITIES (YELLOWSTONE NATIONAL PARK)[a]

Establishment	Unit	Flow (gpd/unit)
Campground (developed)	person	25
Lodge or Cabins	person	50
Hotel	person	75
Trailer Village	person	35
Dormitories, Bunkhouse	person	50
Residence homes and apartments	person	75
Mess hall	person	15
Offices and stores	employee	25
Visitor centers	visitor	5
Cafeteria	table seats	150
Dining room	table seats	150
Coffee shop	counter seats	250
Cocktail lounge	seat	20
Laundromat	washing machine	500
Hospital	bed	200
Gas station	station	2000-5000
Fish cleaning station	station	7500

[a]Source: Metcalf and Eddy Inc., "Wastewater Engineering: Collection, Treatment, Disposal," McGraw-Hill, 1972.

sewers and building connections, intensity of rain and elevation of groundwater compared to that of sewers. While reviewing various specification allowances, Velzy and Sprague (103) reported the greatest percentage of specified allowable infiltration rates. The ranges of these rates are presented in Table 4.2.

TABLE 4.2

INFILTRATION ALLOWANCES FOR SANITARY SEWERS[a]

Pipe Size (inch)	Infiltration rate range (gpd/mile)
8	3500 - 5000
12	4500 - 6000
24	10000 -12000

[a]Source: C. R. Velzy and J. H. Sprague. "Infiltration Specifications and Tests," Sewage and Industrial Wastes, Vol. 17, No. 3, 1955.

The immediate effect of rainwater in gravity collection systems at several treatment plants has been reported by Seymour (75). Figures 4.4 and 4.5 show the infiltration flow pattern at Brunswick Village Treatment plant and at Oakhallow Estate Treatment Plant as reported by Seymour (75). The Texas State Department of Health will not approve a collection system having an infiltration rate exceeding 1000 gallons per inch diameter per mile of pipe in 24 hours (86).

However, infiltration may be reduced to a negligible amount in properly constructed and maintained sewers (53). Infiltration is also

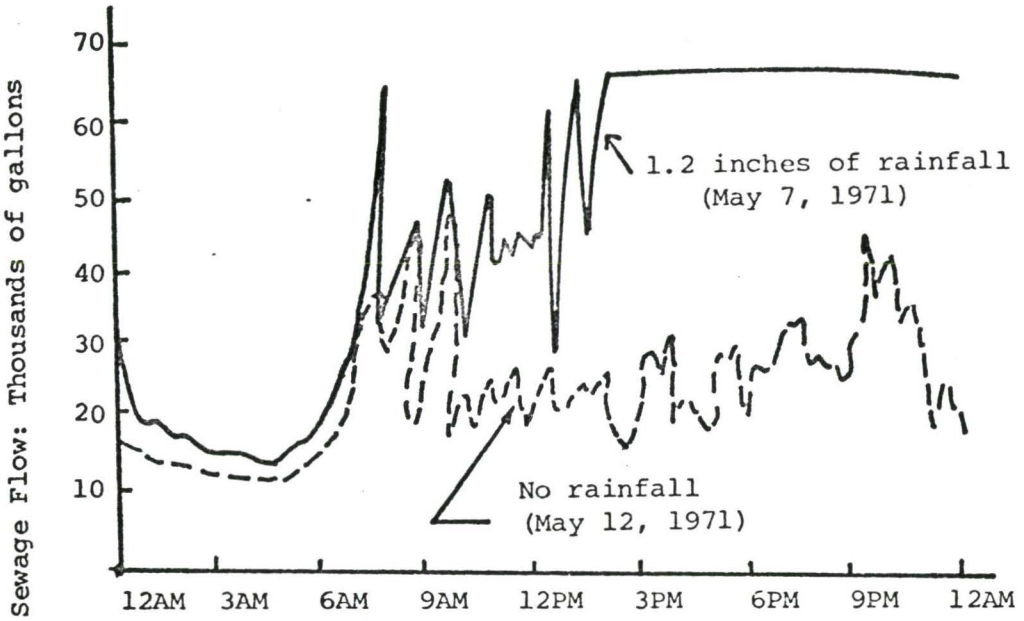

Figure 4.4. Dry weather and infiltration flow pattern at Brunswick Village Package Treatment Plant. (Source: G. G. Seymour, "Operation and Performance of Package Treatment Plants," Journal WPCF, Vol. 44, No. 2, February, 1972.)

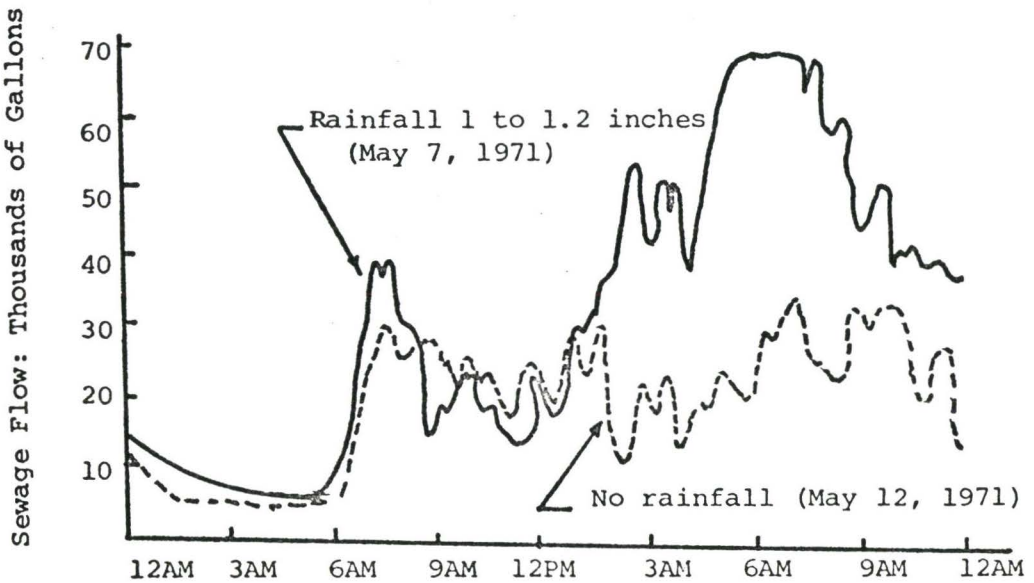

Figure 4.5. Dryweather and infiltration flow pattern at Oakhallow Estates Package Treatment Plant. (Source: G. G. Seymour, "Operation and Performance of Package Treatment Plants," Journal WPCF, Vol. 44, No. 2, February, 1972.)

affected by the collection method. Although conventional gravity sewers may receive much infiltration through manholes, cracks along the pipes and through leakage at joints, infiltration is almost eliminated with pressure sewer systems (6). As relevant data to integrate soil characteristics, groundwater level, topography, etc. were not available for White River Lake to estimate daily infiltration, and since rainfall and collection alternative are the major variables which influence the infiltration, it was assumed that infiltration is a function of daily rainfall and type of collection method only. Mathematically,

$$T_{i,c} = \hat{T}_i * \S_c * R_i * Z_{i,t} \qquad [4.10]$$

where $T_{i,c}$ = Amount of infiltration into collection system c on day i

$\hat{T}_i$ = Estimated amount of infiltration into a collection system built with average workmanship and under average maintenance practice at 1.0" rainfall in gallons per day per mile length of collection pipe.

$\S_c$ = Infiltration coefficient of collection system c.

R_i = Rain on day i.

Z_i = Length of collection pipe on day i, year t.

In Equation [4.10] infiltration is assumed to be linear function of rainfall. As most researchers (6) and manufacturers of pressure collection facilities (22) claim that the infiltration rate for pressure systems is negligible, $\S_c$ for the pressure collection method may

be assumed to be zero. On the other hand, $\S_c$ for a gravity sewer system may be assumed to be 1, if $\hat{T}_i$ is estimated from available data of a gravity collection system. There is no exact method to estimate T_i. However, the experimental results on dry weather and infiltration flow characteristics of several sites, as reported by Seymour (75) may be used as a basis to estimate T_i.

Equation [4.9], therefore, may be rewritten as

$$S_{i,t,c} = \sum_{q=1}^{n_q} P_q V_{q,i,t} + \sum_{s=1}^{n_s} U_s N_s + \hat{T}_i \S_c R_i Z_{i,t} \qquad [4.11]$$

where $\S_c$ = 0 for a pressure collection system

= 1 for a gravity sewer

and $S_{i,t,c}$ = Predicted volume of sewage on day i, year t with collection system c and all other variables have their usual notation previously defined in Equation [4.8] and [4.92].

The computer program for this submodel works as follows:

i) daily visitation output from the "Visitation" component is used to determine the amount of sewage from the sources in Category A.

ii) N_s and U_s data are used to calculate the amount of sewage from sources in Category B.

iii) Values of $\hat{T}_i$, $\S_c$, R_i and Z_i are used to calculate the infiltration into the sewer system on day i.

iv) The above three components of sewage are summed in order to find total amount of sewage on day i.

Collection Methods

The purpose of this section is to evaluate the design of a collection system and relate the collection system to other components of the system. As shown in Figure 4.6, the collection system design and its associated costs depend on sewage volume, soil characteristics, topography, infiltration, and spread of sewage sources. For any projected system design, consideration must be given to i) geographical location, ii) type of development, iii) topography of service area, iv) layout of service area (lots, structures, roads), v) local sewage flow rates, vi) location of treatment facility, vii) area soil conditions, viii) applicable local codes and regulations, ix) service area development sequence, and x) available electric power. Since all of this information concerns the physical characteristics of a specific site, no general methodology can be specified to estimate the collection cost. On the other hand, this part of the model needs special attention to design a collection system specifically for the site under consideration. This study, as mentioned in the stated purpose of the work attempts to evaluate the cost effectiveness of two collection alternatives. These are i) the recently innovated low pressure conveyance system and ii) the conventional gravity collection system. Some of the major design considerations for each of these methods are discussed in the following sections.

Low Pressure Conveyance System

The basic concept behind this collection method is to install a specially designed grinder pump near each source or a concentrated

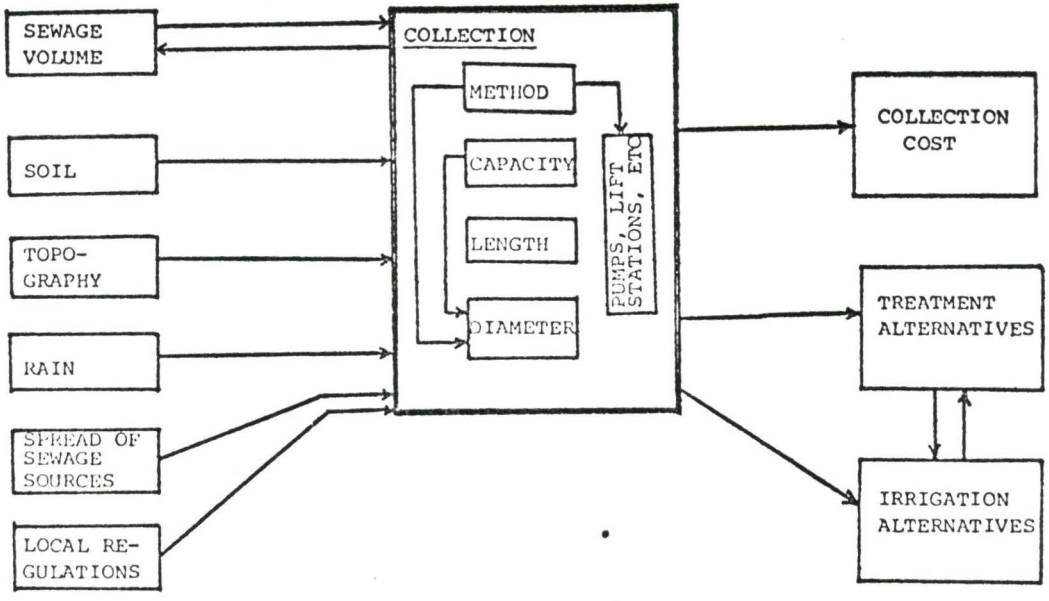

Figure 4.6. Schematic diagram showing various inputs, outputs and feedbacks in the sewage collection component.

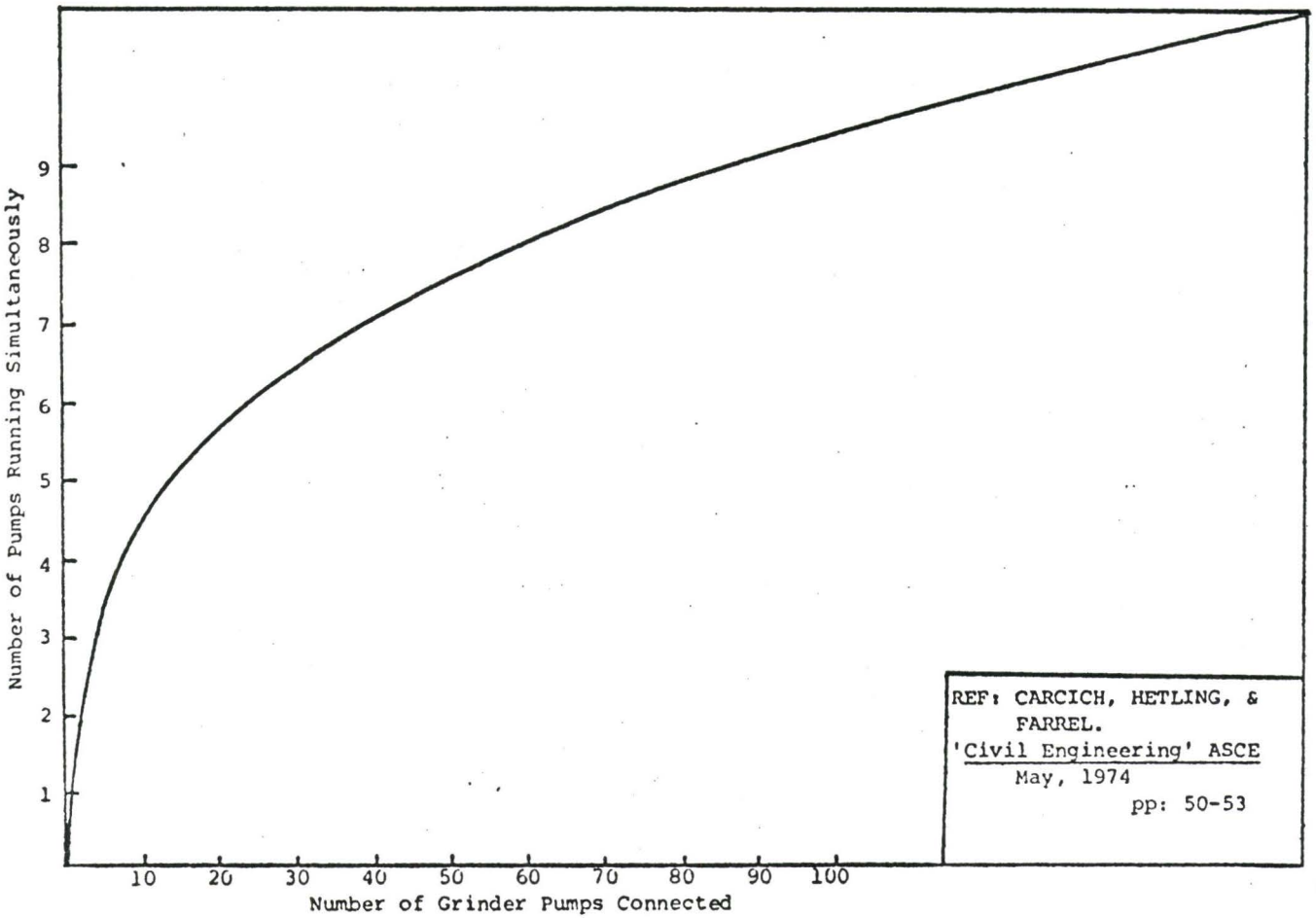

Figure 4.7. Number of pumps connected versus number of pumps in simultaneous opn.

group of sewage sources to grind the large particles in the sewage and then to convey the wastewater through a relatively small diameter pipe at low pressure. As pressure systems are not dependent upon gravity flow, they are free from rigorous constraints of sewer grade and alignment. Although relatively simple to design, the low pressure system has specific requirements which cannot be violated.

System Layout and Alignment. Since branching reduces the problems of possible malfunctions of the entire collection system, and since it is more convenient to locate an exact trouble spot with branch layout, any kind of "looping" has to be carefully avoided. To minimize air-plating of deposited solids in empty runs of pipe, all system lines need to be kept full and under positive pressure head.

Design Flow and Line Sizing. As in any collection system, a pressure sewer system has to be designed to effectively handle all sewage flow generated in the service area, especially during times of maximum sewage generation (peak flows). The maximum flow depends on how many of the grinder pump units connected to the system are expected to operate simultaneously, i.e., the combined rates of the pumps in parallel operation. This is a critical factor in designing a pressure sewer system as traditional methods of estimating peak flow for a service area available for gravity flow collection system will not apply to the design requirements of a pressure collection system. This collection method is still in the developing stage and few research reports on details of its design are available in the literature. In the Albany demonstration project (6) designers assumed that six out of

the twelve grinder pumps connected to a street main would operate simultaneously at least once a day. As it turned out, though, only rarely did more than three pumps operate simultaneously.

However, experimental data from the Albany project provided information on the number of pumps operating simultaneously versus the total number of houses in the development serviced by the pressure sewer system. While some of the researchers suggested that this ratio method be used as the basis for design criteria, there is evidence that some manufacturers are inclined towards using the traditional methods of estimating the peak flow, such as application of water consumption data, known sewage flow data, application of standard peak to average flow ratio, or application of derived peak to average flow ratio based on population. Some of these manufacturers provide their own design flow tables for various establishments (40).

Once the peak flow is determined, the next step is to consider the conduit sizing. In any sewer system, sewage flow may fluctuate greatly during the course of a 24-hour period. During periods of low or zero flow, sewage solids deposit in the collection line. The scouring of these deposits is very important to prevent a potential clogging problem in smaller diameter pressure lines. Experimental results, using typical domestic ground raw sewage, have shown that the velocities in the range of 2 ft/sec to 5 ft/sec at some regular interval are needed to insure scouring of these solid deposits (40). The pipe sizing, therefore, has to be small enough to insure that scouring velocity of at least 2 ft/sec occurs at regular intervals. At the

same time the pipe sizing has to be large enough to avoid the situation of excessive system pressures which can affect the normal delivery of any individual grinder pump connected to the system.

Line size, therefore, has to be an efficient compromise among i) economics, ii) scouring requirements and iii) system pressure limitations.

One of the most important design considerations is that proper operation of each grinder pump be assured at all times.

Standard designs for pressure sewer systems call for normal operating pressures to be in the 35 psi range. As a precaution, grinder pumps are selected to have reserve pumping range of at least 40 percent above the system's maximum pressure to assure purging when needed (40). The discharge line from the grinder pump (home service line to main) is seldom above 1¼ inches. The main is usually 2 inches at the extreme ends of each branch and increases in diameter as the load increases toward the disposal point. Schedule 40 or SDR-21 pipe is commonly specified for the system.

Gravity Flow Collection System

Since this is the traditional method of sewage collection, design practices and criteria for installation are reasonably well documented in the literature (53). The principle behind this collection method is to lay the pipes with specified downward slope so that the wastewater flows by gravity towards the treatment plant. Manning's or Kutter's equations (53) are usually used for sewer design. However,

most of the time, especially for small residential communities, the design factors are limited by local standards. For example, the Texas State Department of Health (86) does not approve any sewers other than house laterals to be less than six inches in diameter. The adoption of minimum size of sewer is necessary to avoid any possible and frequent clogging of the pipes by comparatively large objects such as rags and scrub brushes. As already mentioned, all sewers have to be designed and constructed with hydraulic slopes sufficient to give mean velocities when flowing full or half full of not less than 2.0 feet per second. The minimum slopes as shown in Table 4.3 are standards set by Texas State Department of Health (86).

TABLE 4.3

MINIMUM SLOPES FOR SANITARY SEWERS

Size of Pipe (in inches I.D.)	Fall in Feet (per 100 feet of Sewer)
6	0.60
8	0.40
10	0.29
12	0.22
15	0.16
18	0.12
21	0.10
24	0.08
27	0.06
30	0.055

Other major components of these conveyance systems are manholes and lift stations. In addition to these, a wide variety of special appurtenant structures are required. Since detailed descriptive

materials on all of these items are well documented in the literature, this section will not describe this collection method any further. Moreover, the overall system model for sewage collection-treatment-and disposal in this study is not directly connected to sewer design. The primary interest in collection systems only concerns the associated construction and operation costs along with the daily volume of wastewater collected. Cost elements associated with each of these two collection methods are:

Pressure Collection	Gravity Collection
i) Installation cost of collection pipes	i) Installation cost of collection pipes.
ii) Cost of the grinder pumps (installed)	ii) Costs for manholes, lift-stations etc. (installed)
iii) Operation costs: annual power cost by the grinder pumps; maintenance cost; replacement cost of sewers and grinder pumps; replacement costs for other components like valve boxes, flushing device etc.	iii) Operation costs: power costs for lift stations; maintenance costs; replacement costs etc.

Once both of the collection systems are designed specifically for the site under consideration for various projected development rate, the associated costs may be estimated by contacting local manufacturers of collection facilities and consultant engineers. An evaluation of the economics of collection methods will be further discussed while developing the "decision process" at the end of this chapter.

Treatment Alternatives

The purpose of this component submodel is to incorporate the costs and pollutant-removal efficiencies of various treatment

alternatives in the analysis process for identifying the most economic collection-treatment and disposal decision. Categories of treatment methods to be evaluated in this study are primary treatment, various secondary treatment plants such as stabilization ponds, high rate trickling filters, standard rate trickling filters, activated sludge plants, package plants and/or any of their feasible combinations. Since there are numerous alternative designs for each category of the above-mentioned treatment plants, no attempt will be made in this model to specifically design any of the treatment plants. On the other hand, each of the treatment alternative methods to be compared will be rather considered as a "black box" as shown in Figure 4.8. Standard cost estimation techniques based on average designs and performances, as provided in the literature, are used to determine various cost elements associated with each treatment category. Cost estimating procedures were discussed previously in Chapter 3. Most of these cost estimating techniques are based upon national average figures in some specific time period. There are various methods available to adjust and update these cost elements for some specific region. To account for possible regional differences, 20 U.S. regions have been defined. Each region corresponds to one of the 20 cities used in obtaining the United States Average Engineering News-Record Construction Cost Index (ENR-C Index). Cost indexes for the areas of influence of 20 major trade centers are helpful in comparing the costs on a regional and time basis. Because the FWPLA Sewage Treatment Plant Construction Cost Index (WPC-STP Index) is based on information

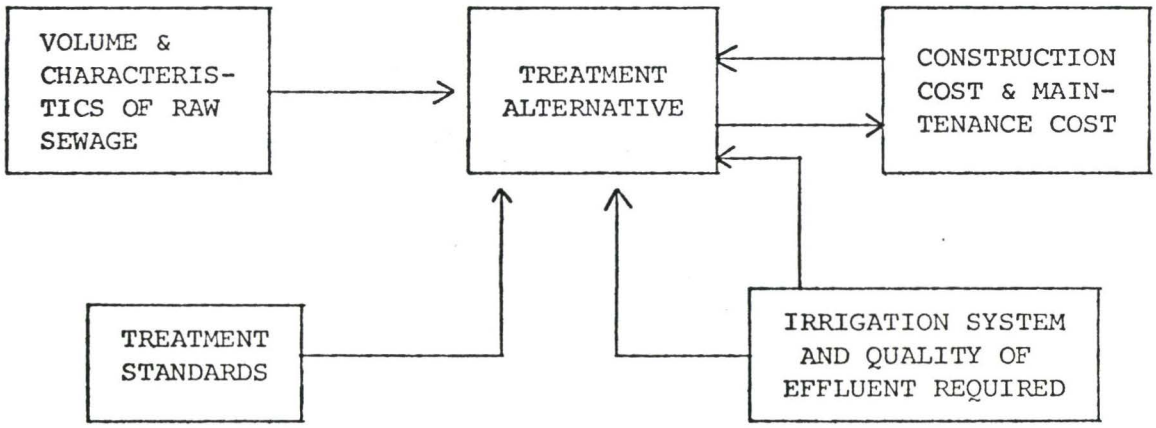
VOLUME & CHARACTERIS-TICS OF RAW SEWAGE
TREATMENT ALTERNATIVE
CONSTRUCTION COST & MAIN-TENANCE COST
TREATMENT STANDARDS
IRRIGATION SYSTEM AND QUALITY OF EFFLUENT REQUIRED

Figure 4.8. Schematic diagram of submodel "Treatment Alternative."

specific to wastewater treatment plant construction, its usefulness for evaluating the construction costs of waste treatment plant is much greater than the ENR-C index. Therefore, this study uses the WPC-STP Index to adjust the cost data of treatment plants for a specific site. The U.S. Department of Labor's estimates of Average Earnings for Nonsupervisory-Workers in Water, Steam and Sanitary Systems (96) are used to update various elements of operating and maintenance costs.

Soil Moisture Balance

The basic purpose of using a Soil Moisture Balance Submodel is to incorporate rain, pan evaporation, soil properties, shade trees and grass varieties, and various irrigation and planting strategies in order to evaluate the economics of alternative decisions. The soil moisture balance for this study is based upon the findings and ideas presented by Mapp (52), Van Bavel (100), Denmead and Shaw (17), Texas Water Development Board (87), Thornwaite (91), Thornwaite and Mather (92), Holmes and Robinson (39), and Ligon et al. (50).

The water available to a plant can be regarded as being stored in a soil moisture reservoir. The water that a plant uses is extracted from this reservoir as shown in Figure 4.9. The capacity of the soil moisture reservoir is limited by the total amount of water it can hold between field capacity and the wilting plant (Figure 4.11). Field capacity is defined as the amount of water a well-drained soil holds after free water has been drained off; or the maximum amount of

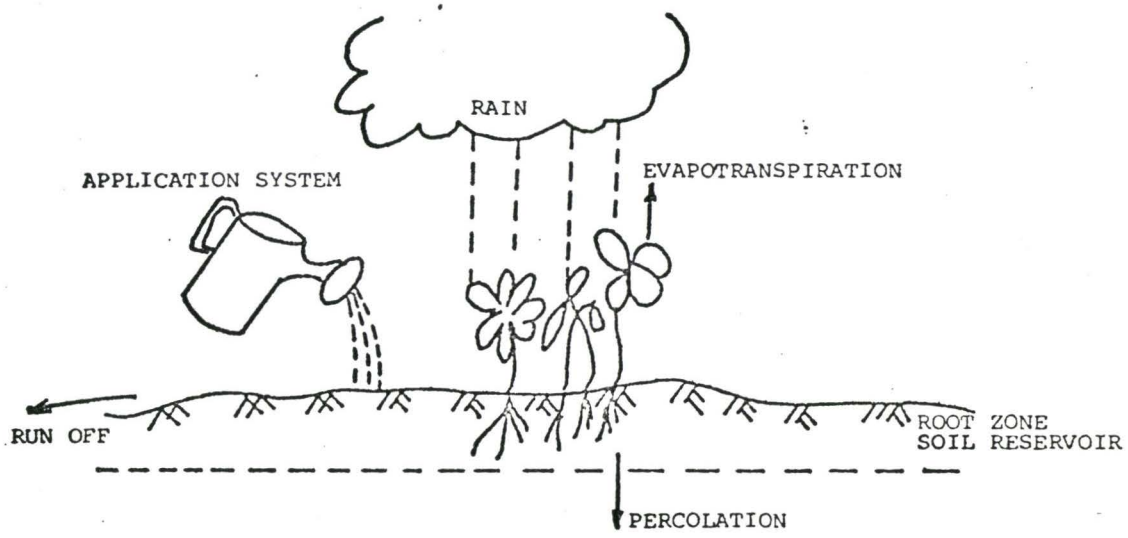

Figure 4.9. Schematic diagram of an irrigation system.

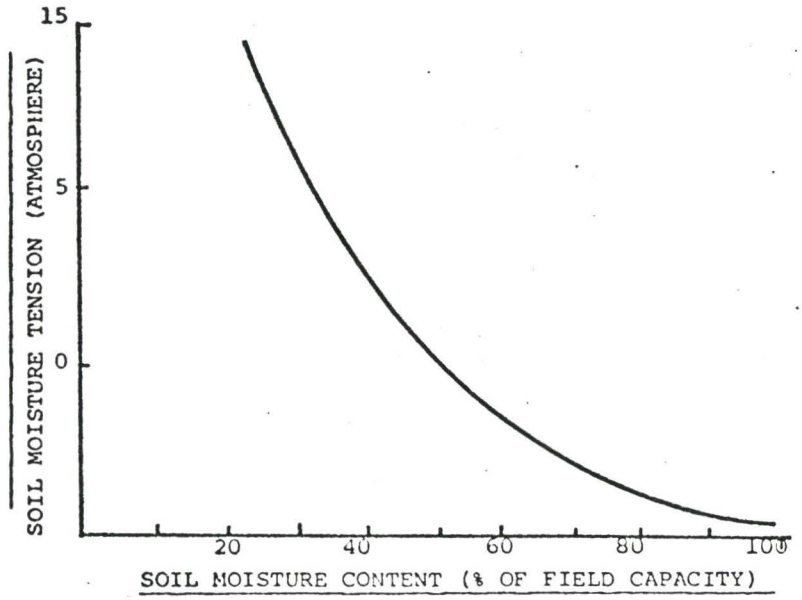

Figure 4.10. Typical soil moisture relationship. (Source: Saymond J. Burby, "A Quantitative Analysis of Factors Influencing Residential Location in Reservation Recreation Areas," Journal of Leisure Research, Vol. 3 (Spring, 1971), No. 2.)

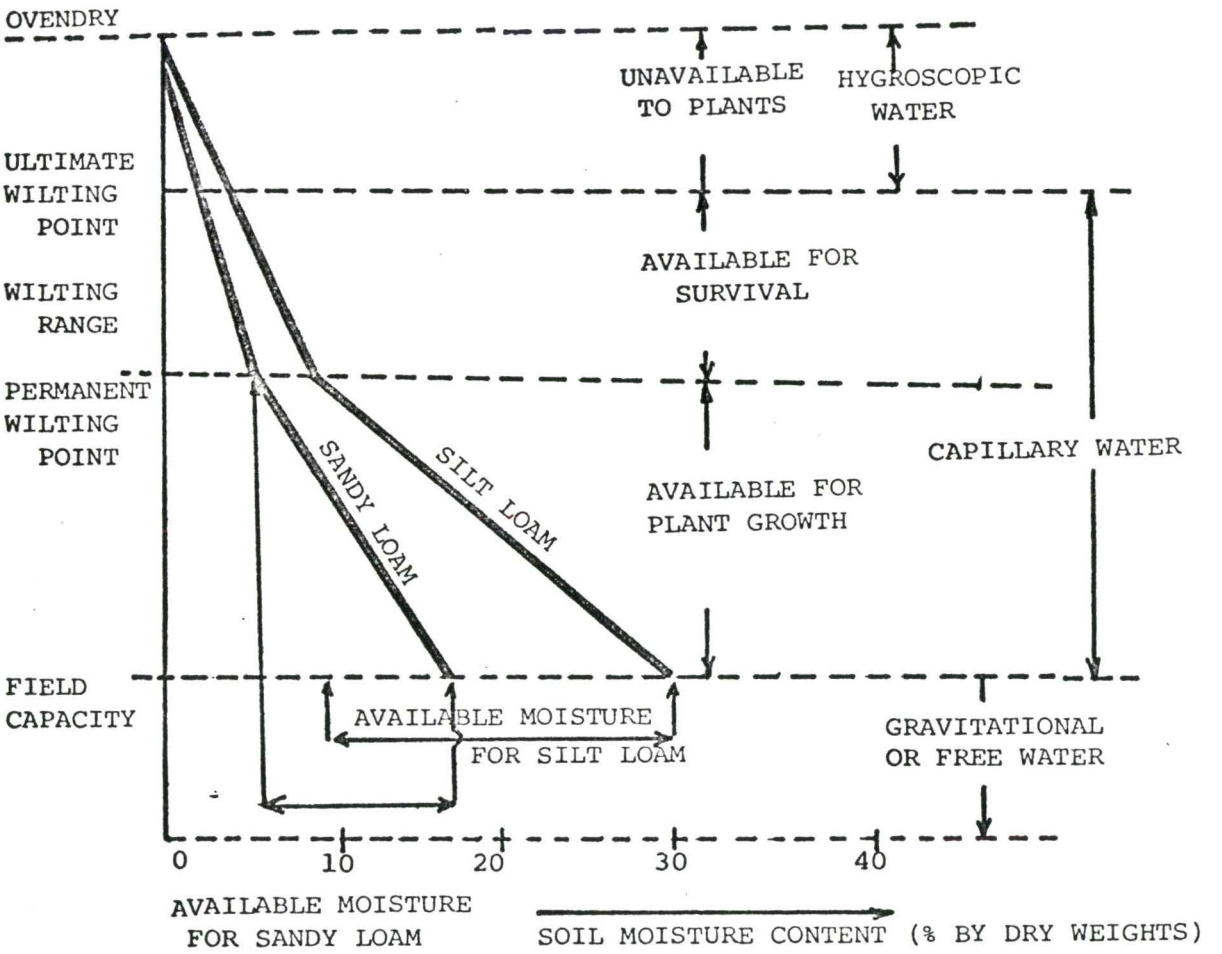

Figure 4.11. Kinds of water in the soil and differences in available moisture content between a sandy loam and a silt loam.

water it can hold against gravity (87). The permanent wilting point is the soil moisture at which plants can no longer extract water to meet the transpiration requirements (87).

A portion of the water in the root zone may percolate below the root system. While consumptive use of the plant and percolation losses lower the content of the soil moisture reservoir, rainfall and irrigation application have the opposite effect. If soil moisture is not replenished by irrigation, the amount of soil moisture in day i, in soil j, at the root zone of a plant of type k may be expressed as follows (52, 87):

$$SM_{i,j,k} = SM_{i-1,j,k} + R_i - L_{i,j} - F_i - U_{i,j,k} \qquad [4.12]$$

where R_i = rain on the i'th day

$L_{i,j}$ = percolation loss on day i, from soil j

F_i = runoff loss on day i

$U_{i,j,k}$ = consumptive use by a plant of type k from soil j on day i.

Consumptive use of a plant, $U_{i,j,k,}$ may be explained in terms of evapotranspiration. There are two concepts of evapotranspiration: potential evapotranspiration and actual evapotranspiration. Potential evapotranspiration is the amount of soil moisture evaporated or transpired by a plant at a particular stage of development under adequate soil moisture conditions (52). Daily amount of potential evapotranspiration may be estimated as a function of daily pan evaporation readings. Actual evapotranspiration indicates the evapotranspiration which actually occurs in a day. This is a function of potential

evapotranspiration, soil moisture conditions and physical properties of the soil. At the wilting point, a plant cannot transpire any moisture from the soil, in which case actual evapotranspiration may be assumed to be zero. On the other hand, actual evapotranspiration equals the amount of potential evapotranspiration when the soil moisture is at field capacity. Once the soil moisture falls below field capacity, actual evapotranspiration may be assumed to be proportional to the potential evapotranspiration. Mathematically,

$$AE_{i,j,k} = 0 \text{ if } SM_{i-j,\ j,k} \leq W_j \qquad [4.13]$$

$$= PE_{i,j,k} \text{ if } SM_{i-1,j,k} = FC_j \qquad [4.14]$$

$$= \frac{1}{FC_j - W_j} [SM_{i-1,j,k} - W_j]$$

$$\text{if } W_j < SM_{i-1,j,k} < FC_j \qquad [4.15]$$

where $AE_{i,j,k}$ = Actual evapotranspiration on day i in soil j by a plant of k'th type

$PE_{i,j,k}$ = Potential evapotranspiration on day i, soil j by a plant of k'th type

W_j = Wilting point of soil j

FC_j = Field capacity of soil j

Potential evapotranspiration ($PE_{i,j,k}$) may be assumed to be a function of pan evaporation as follows:

$$PE_{i,j,k} = K_{i,j,k}\ PAN_i \qquad [4.16]$$

where PAN_i = Pan evaporation on i'th day

$K_{i,j,k}$ = Consumptive use coefficient on day i, soil j, for a plant of type k.

Equation [4.12] can thus be rewritten as follows:

$$SM_{i,j,k} = SM_{i-1,j,k} + R_i - L_{i,j} - F_i \quad \text{if } SM_{i-1,j,k} \leq W_j \qquad [4.17]$$

$$= SM_{i-1,j,k} + R_i - L_{i,j} - F_i - K_{i,j,k} PAN_i$$

$$\text{if } SM_{i-1,j,k} = FC_j \qquad [4.18]$$

$$= SM_{i-1,j,k} + R_i - L_{i,j} - F_i - \frac{(SM_{i-1,j,k} - W_j)}{FC_j - W_j} K_{i,j,k} PAN$$

$$[4.19]$$

$$\text{if } W_j < SM_{i-1,j,k} < FC_j$$

Values of $K_{i,j,k}$ for different varieties of grass at various growth stages are available in different sources. However, few research studies on the consumptive use of various types of shade trees are available. Only limited research work on the consumptive use of orchard trees has been done in the USA and Israel (42, 67). These studies have related the consumptive use of orchard trees to canopy size. Suggestions from manufacturers of irrigation facilities and other experts in irrigation were considered in this study in estimating $K_{i,j,k}$ values for the shade trees under consideration. A relatively detailed discussion on this subject will be included in Chapter 5 in describing the application of the model to the case study

area. Procedures to estimate other parameters entailed in the above sets of equations are discussed at the end of this section.

Mathematical expressions for soil moisture in equations [4.17], [4.18] and in [4.19] were used to develop a methodology for the determination of daily irrigation requirements as follows.

As shown in Figure 4.10, a reduction in soil moisture increases the moisture tension. This moisture stress puts a strain on the plant and affects its potential growth. To avoid this damage, the soil moisture must not fall below a specific level at which the plant would potentially be damaged. When soil moisture approaches the severe stress level, the usual practice is to irrigate the fields and replace the soil moisture (87). On the other hand, the maximum possible irrigation application is limited by the field capacity of soil. However, on some specific sites such as campgrounds, it may not be desirable to irrigate the soil up to field capacity in order to avoid dampness of the ground surface. Therefore, the upper and lower bounds on the amount of irrigation application may be expressed as:

$$I^{min}_{i,j,k,m} = \delta_{j,m} \left(\bar{a}_{j,k,m}\, FC_j - SM_{i,j,k}\right) \qquad [4.20]$$

$$I^{max}_{i,j,k,m} = \delta_{j,m} \left(a_{j,k,m}\, FC_j - SM_{i,j,k}\right) \qquad [4.21]$$

where $I^{min}_{i,j,k,m}$ = minimum amount of irrigation application required on day i, soil j, for a plant of type k, by using the m'th irrigation alternative.

$I^{max}_{i,j,k,m}$ = maximum possible amount of irrigation application on

day i, soil j, for a plant of type k, by using m'th irrigation alternative.

$\delta_{j,m}$ = Irrigation efficiency of the m'th irrigation alternative on j'th soil,

$\underline{a}_{j,k,m}$ and $a_{j,k,m}$ are the minimum and maximum level of soil moisture (expressed in percent of field capacity) which are permitted by soil j, plant k, and irrigation alternative m, respectively.

Equations [4.20] and [4.21] represent the lower and upper bounds of irrigation application for a single shade tree. Since in practice it is neither usual nor convenient to express the irrigation requirement of a grassed area in terms of a single plant, these equations do not apply in determining the bounds of irrigation application for lawns. The lawns or grasslands to be irrigated have to be evaluated on the basis of area covered. Thus the corresponding bounds for irrigating an acre of grass may be expressed as follows:

$$\underline{I}^{min}_{i,j,g,n} = \delta_{j,n} \left(\underline{al}_{j,g,n} FC_j - \overline{SM}_{i,j,g}\right) \qquad [4.22]$$

$$\underline{I}^{max}_{i,j,g,n} = \delta_{j,n} \left(al_{j,g,n} FC_j - \overline{SM}_{i,j,g}\right) \qquad [4.23]$$

where

$$\overline{SM}_{i,j,g} = \overline{SM}_{i-1,j,g} + R_i - L_{i,j} - F_i \text{ if } \overline{SM}_{i-1,j,g} \leq W_j \qquad [4.24]$$

$$= \overline{SM}_{i-1,j,g} + R_i - L_{i,j} - F_i - \overline{K}_{i,j,g} PAN_i$$

$$\text{if } \overline{SM}_{i-1,j,g} = FC_j \qquad [4.25]$$

$$= \overline{SM}_{i-1,j,g} + R_i - L_{i,j} - F_i - \frac{(\overline{SM}_{i-1,j,g} - W_j)}{FC_j - W_j} \overline{K}_{i,j,g} PAN_i$$

$$\text{if } W_j < \overline{SM}_{i,j,g} < FC_j$$

and $\overline{I}^{min}_{i,j,g,n}$ = minimum amount of irrigation required on day i, by an acre of g'th grass cover on soil j, using irrigation alternative n.

$\overline{I}^{max}_{i,j,g,n}$ = maximum irrigation possible on day i for an acre of g'th grass cover on soil j by using the n'th irrigation technique

$\overline{SM}_{i,j,g}$ = soil moisture under an acre of g'th grass cover on day i, soil j.

$\overline{al}_{g,j,m}$ = minimum level of soil moisture which may be permitted on soil j, grass g and irrigation technique n.

$\overline{a2}_{g,j,m}$ = maximum level of soil moisture which may be permitted on soil j, grass g, and irrigation technique n.

$\overline{K}_{i,j,g}$ = consumptive use coefficient in day i, soil j, for an acre of g'th grass cover.

Now let p^p be the p'th vegetation strategy denoting the numbers and varieties of shade trees and acres of grass land to be developed on various soil so that

$$p^p \in (N^p_{j,k'}, \overline{N}^p_{j,g}) \text{ for } p = 1, 2, \ldots n_p \qquad [4.26]$$

n_p being the number of various planting decisions to be evaluated.

where

$N^p_{j,k}$ = Number of k'th type trees to be grown on soil j according to planting decision p

$\overline{N}^p_{j,g}$ = Number of acres to be used for grass type g, on soil j, according to planting decision p.

The upper and lower bounds on total irrigation application throughout the entire irrigation field according to p'th planting decision on day i for all trees and lawns are given by:

$$II^{max}_{i,m,n,p} = \sum_{j=1}^{m_p} \sum_{k=1}^{t_p} N^p_{j,k} \; I^{max}_{i,j,k,m} + \sum_{j=1}^{m_p} \sum_{g=1}^{g_p} \overline{N}^p_{j,g} \; \overline{I}^{max}_{i,j,g,n} \qquad [4.27]$$

$$= \sum_{j=1}^{m_p} \sum_{k=1}^{t_p} N^p_{j,k} \; \delta_{j,k} \; (a_{j,k,m} \; FC_j - SM_{i,j,k}) + \qquad [4.28]$$

$$\sum_{j=1}^{m_p} \sum_{g-1}^{g_p} \overline{N}^p_{j,g} \; \delta_{j,g} \; (\overline{al}_{j,g,n} \; FC_j - \overline{SM}_{i,j,g})$$

$$II^{min}_{i,m,n,p} = \sum_{j=1}^{m_p} \sum_{k=1}^{t_p} N^p_{j,k} \; I^{min}_{i,j,k,m} + \qquad [4.29]$$

$$\sum_{j=1}^{m_p} \sum_{g=1}^{g_p} \overline{N}^p_{j,g} \; \overline{I}^{min}_{i,j,g,n}$$

$$= \sum_{j=1}^{p} \sum_{k=1}^{m} N^{p}_{j,k} \; \delta_{j,k} \; (\overline{a}_{j,k,m} \; FC_j - SM_{i,j,k}) +$$

$$\sum_{j=1}^{p} \sum_{g=1}^{n} \overline{N}^{p}_{j,g} \; \delta_{j,k} \; (\overline{al}_{j,g,n} \; FC_j - \overline{SM}_{i,j,g}) \qquad [4.20]$$

where $II^{max}_{i,m,n,p}$ = Maximum irrigation permitted on day i over the entire irrigation area according to vegetation strategy p by using m and n'th irrigation techniques for shade trees and grass lands, respectively.

$II^{min}_{i,m,n,p}$ = Minimum amount of irrigation needed on day i, according to vegetation strategy p by using m'th and n'th irrigation techniques.

m_p = Total number of soil varieties considered for vegetation strategy p.

t_p = Total number of tree types considered for vegetation strategy p.

g_p = Total number of grass varieties considered for vegetation strategy p.

Now let CAP be the capacity of the effluent storage, SR_i be the volume of elluent in storage on day i, and $E_{i,o,t}$ be the amount of effluent available on day i, from treatment plant alternative o and collection system c.

Each day one of the following four cases may occur:

Case 1: Effluent Excess. The storage facility is full and the irrigation fields do not require any more applications. Operating

rules may be employed to dispose of the excess treated effluent outside system as follows:

$$D^{p}_{i,m,n,o,r} = E_{i,o,c} \quad II^{max}_{i,m,n,p} - (CAP - SR_{i-1}) \qquad [4.31]$$

$$\text{if } E_{i,o,c} > III^{max}_{i,m,n,p} + (CAP - SR_{i-1})$$

$$= 0 \text{ otherwise}$$

where $D^{p}_{i,m,n,o,c}$ = Volume of effluent to be disposed of on day i, for planting pattern p, using m'th and n'th irrigation techniques for trees and grass respectively, with treatment alternative o, and r'th collection alternatives.

Since the storage is full and the fields have been irrigated up to the maximum permitted level

$$SM_{i,j,k} = a_{i,j,k} \, FC_{j} \qquad [4.32]$$

and

$$\overline{SM}_{i,j,g} = al_{i,j,g} \, FC_{j} \qquad [4.33]$$

$$SR_{i} = CAP \qquad [4.34]$$

Case 2: Effluent Deficit. In this case, the effluent available from the treatment plant along with the effluent in storage is not sufficient to meet the minimum irrigation requirement. Water from the lake, therefore, has to be pumped for irrigation. Volume of water to be pumped from the lake is

$$p^{p}_{i,m,n,o,c} = II^{min}_{i,m,n,p} - (E_{i,o,c} + SR_{1-1})$$

[4.23]

$$\text{if } E_{i,o,c} < II^{min}_{i,m,n,p} - SR_{i-1}$$

$$= 0, \text{ otherwise}$$

where $p^{p}_{i,m,n,o,r}$ is the amount of water to be pumped from the lake and where i,m,n,o,p, and r have their usual notation described before. Subsequently,

$$SR_i = 0 \qquad [4.36]$$

$$SM_{i,j,k} = \overline{a}_{i,j,k}\, FC_j \qquad [4.37]$$

$$\overline{SM}_{i,j,g} = \overline{al}_{i,j,g}\, FC_j \qquad [4.38]$$

Case 3: Store Excess Effluent. In this case total available effluent on day i is greater than the maximum permittable irrigation but enough storage is available so that

$$SR_i = SR_{i-1} + E_{i,o,c} - II^{max}_{i,m,n,p}$$

$$\text{if } II^{max}_{i,m,n,p} < E_i + SR_{i-1} < II^{max}_{i,m,n,p} + (CAP - SR_{i-1})$$

[4.39]

and

$$SM_{i,j,k} = a_{i,j,k}\, FC_j \qquad [4.40]$$

$$SM_{i,j,g} = al_{i,j,g}\, FC_j \qquad [4.41]$$

Case 4: Effluent Corresponds to Irrigation Requirements. Total available effluent from the treatment plant and from storage is within the upper and lower bounds of irrigation application. In this situation the operating rule may be to use all of the available effluent for irrigation. Consequently, $II_{i,m,n,p}$, the irrigation application on day i, equals the amount of available effluent.

$$II_{i,m,n,p} = E_{i,o,c} + SR_{i-1}$$

$$\text{if } II^{min}_{i,m,n,c} < E_{i,o,c} + SR_{i-1} < II^{max}_{i,m,n,p} \qquad [4.42]$$

and

$$SR_i = 0$$

$$SM_{i,j,k} = SM_{i,j,g} = \alpha FC_j \qquad [4.43]$$

where all the trees and lawns are so irrigated that the soil moisture is at α percent of field capacity.

The relationships among irrigation methods, irrigation requirements and vegetation to be grown along with soil characteristics, treatment and collection alternatives have been developed in the above part of this section. Procedures to estimate various parameters involved in these relationships are discussed below. The parameters are $K_{i,j,k}$, FC_j, W_j, R_i, PAN_i, F_i, $L_{i,j}$, $\delta_{j,m}$, $al_{j,k,m}$, $a2_{j,k,m}$, and $\overline{a2}_{j,k,m}$.

One of the common difficulties in estimating these parameters is that they are highly dependent on local soil characteristics, topography and irrigation practice. Long time experimentations at a specific site, which are not common, are needed to determine these values. The only other feasible way is either to assume these parameters to be equal to the values reported by researchers at other similar sites, or to consult local irrigation experts and manufacturers of irrigation facilities.

Estimation procedures for evapotranspiration coefficients $K_{i,j,k}$ for grass and various shade trees have already been discussed when formulating the yxpressions for soil moistures in Equations [4.13], [4.14], and [4.15] and are further discussed in Chapter 5 while describing the application of the model. FC_j and W_j, the field capacity and wilting point of soil j, respectively, entirely depend on the physical characteristics of local soil. Experimental results of "soil moisture release" tests for local sites are absolutely essential to estimate these values. Local soil conservation service stations may provide information on these experiments. If these estimates are available for local soils, field capacities and wilting points of the soils under consideration may be assumed approximately equal to the values of field capacities and wilting points of similar soils at other sites obtained in soil conservation service offices or from other sources.

Records of daily rainfall and pan evaporation from local weather stations need to be statistically analyzed for estimating R_i and PAN_i.

The analysis techniques are discussed in the respective submodels on rain and pan evaporation in a later part of this chapter.

For simplification it may be assumed that runoff loss, F_i, is zero if the soil moisture is below its field capacity (87). Moreover, runoff loss is directly related to the irrigation method. Since drip irrigation applies water at the rootzone at a very slow rate, surface runoff is almost reduced to zero (87). On the other hand, if water is sprayed at a higher rate than the soil can absorb, which can occur with sprinkler irrigation, some runoff loss will result. Since runoff loss is a function of the irrigation method, a runoff loss coefficient may be implicitly incorporated in the respective irrigation efficiency factor $\delta_{j,m}$. Irrigation efficiency for this purpose may be defined as follows:

$$\delta_{j,m} = \frac{\text{Gallons of water required to apply in soil j, by method m}}{\text{Gallons of water made available at the root zone, in soil j by method m}}$$

Few research studies on the relative efficiencies of drip and sprinkler irrigation for various soil types are available. Some average efficiency data for non-specific soil types are available. Local manufacturers of irrigation facilities and irrigation experts can provide approximate estimates to supplement values obtained from the literature.

Estimation of percolation loss in various soils again requires experimentation at local soils. The usual practice is to aggregate for different soil types and to use an average value of 5 percent of applied water as percolation loss (87).

Values of $\overline{a}_{j,k,m}$, $a_{j,k,m}$, $\overline{al}_{j,k,m}$, $al_{j,k,m}$ entirely depend on the management practices, types of trees and grasses to be grown and local soil characteristics. In order to estimate these values, local irrigation experts have to be consulted.

Rainfall and Pan Evaporation

To simulate daily soil moisture for the planning period, some method is needed to generate daily rainfall and pan evaporation at the site. Historical rainfall and pan evaporation data at the site need to be statistically analyzed in order to formulate appropriate submodels.

In order to formulate appropriate submodels for generating rain and pan evaporation, each year is first divided into 12 monthly periods. Past records on daily rainfall and pan evaporation for each period are then analyzed in turn, as follows:

Step 1: Test for Correlation. Daily rainfall and pan evaporation values for the period under consideration are tested to investigate the presence of any negative correlation between them. An appropriate nonparametric statistical test for this purpose is Hotelling and Pabst (Modified Spearman Rho) one-tailed test (13).

Step 2: Tests for Randomness: Since normality or nonnormality of the distributions under consideration are not known, any statistical test based on the assumption of normality is invalid. Two such tests, inadmissible for this reason, are those of Von Neuman (104) and Durbin-Watson (15). On the other hand, several nomparametric tests

for randomness are available. Among these are the Wald-Wolfowitz run test (106) and the Wallis-Moore phase tests (107) which are used here.

One of the basic assumptions behind the Wald-Wolfwitz test is that any observation in a series may be placed in two categories (107). Since each day may be classified into "wet" or "dry" categories, depending on the amount of rainfall on that day, the Wald-Wolfowitz test is relatively easy to apply in testing the randomness of daily rainfall. On the other hand, because of the difficulty in defining the two categories, the Wallis-Moore phase test, which does not need any such classification of data, is more feasible to apply in the case of pan evaporation. The Wallis-Moore phase test, being considerably more powerful than the Wald-Wolfowitz run test for determining short run "bunchiness" of data is also useful for daily rainfall analysis (15).

A computer program, as reported by Day (15), written in FORTRAN is available from the University of Wisconsin to facilitate tests for randomness of large bodies of time series data (65). This program includes both the Wald-Wolfowitz test and Wallis-Moore test.

Tests for correlation and randomness, as described in Step 1 and Step 2 respectively, may support any one of the following sets of assumptions for each monthly period:

a. Daily rainfall and Daily pan evaporation } Independent and both random

b. Daily rainfall and Daily pan evaporation } Independent and both nonrandom

c.	Daily rainfall and Daily pan evaporation	} Independent and one of them is nonrandom while other is random
d.	Daily rainfall and Daily pan evaporation	} Correlated and both random
e.	Daily ranfall and Daily pan evaporation	} Correlated and nonrandom

The analysis procedure for each of the above four sets of assumptions is discussed in Step 3 as follows:

Step 3: Case a: Daily Rain and Pan Evaporation are Independent and Random. Since daily rainfall and pan evaporation are independent and random, it is quite reasonable to seek two separate independent distribution functions in past records of daily rainfall and pan evaporation. To identify or to describe the true "parent" distribution function for any natural stochastic process is impossible. The only feasible way is to look for a good approximation to the true distribution function. The usual practice to deal with a weather variable is to fit the past data to some specific theoretical continuous probability distribution, such as lognormal, gamma, incomplete gamma or beta distribution (52). In all of these cases, nonnormality of the "parent" distribution is the a priori hypothesis. Though overwhelming evidence of positive skewness of either daily rainfall or pan evaporation exists in various climatic regions, statistical tests to support any such priori assumption for a specific site may be essential. Two of the most commonly used tests for skewness and kurtosis are Egon-Pearson's test and Geary's test for kurtosis (62).

These "goodness of fit" tests may be thus applied to identify an appropriate distribution function of daily rainfall or pan evaporation in any monthly period of a year. In practice, the true distribution function is seldom exactly the same as the hypothesized one. However, in this case only a good approximation to the true distribution function is necessary and the "goodness of fit" test provides a means of justifying the use of a hypothesized distribution function as the good approximation by the acceptance of H_o.

One important aspect of fitting the daily rainfall and pan evaporation data of different monthly periods into predefined distribution functions is that the ultimate analysis may turn up with different distribution functions according to the period of analysis. For example, daily rainfall in January may fit a lognormal distribution whereas that in March may be described by a different distribution or different values of parameters for the distribution. In order to be efficient in computer use, it is necessary to employ a distribution function which is capable of describing the daily rainfall or pan evaporation for as many monthly periods as possible just by changing the values of parameters. If the distributions are suspected to be positively skewed, the gama distribution is applicable. As the two parameters are varied, the gamma density can assume a wide variety of shapes. Moreover, since daily rain or pan evaporation cannot assume negative values and generally follows a unimodal distribution, the chances are good that a member of the gamma family should adequately describe any of these processes.

However, in some climatic regions particularly those with semiarid conditions, such a high proportion of total probability of daily rainfall may be clustered at or near zero so that no continuous probability distribution satisfactorily approximates the rainfall pattern. In this case, a simple alternative is to construct a discrete empirical probability distribution based on actual daily observations of past rainfall.

Step 3: Case b: Daily Rain and Pan Evaporation are Independent and Both Are Nonrandom. In this situation daily rain and pan evaporation are not random. This suggests that a rainy day tends to follow another rainy day. To construct appropriate models for generating daily rain or pan evaporation in this situation, the following procedure is followed.

At first, in the case of rain, the days are divided into two categories: "dry" with rainfall equal to zero, and "wet" with rainfall greater than zero. It is then assumed that the "dry" or "wet" status of a day and not the amount of rainfall in that day is dependent on the "dry" or "wet" status of the previous day or days. From the analysis of past records on "wet" and "dry" days, the following sets of conditional probabilities are calculated:

$P[R_i > 0 \mid R_{i-1} = 0]$, $P[R_i > 0 \mid R_{i-1} > 01]$, $P[R_i > 0 \mid R_{i-1} > 0, R_{i-2} > 0]$, $P[R_i > 0 \mid R_{i-1} > 0, R_{i-2} > 0, R_{i-3} > 0]$,...

$P[R_i > 0 \mid R_{i-1} > 0, R_{i-2} > 0, \ldots R_{i-n} > 0]$ where n is the maximum number of wet days available to be "bunched" together in the past record.

The next step is to consider only the wet days of past record and to construct a discrete empirical probability distribution for the amount of rainfall in a wet day in the monthly period under consideration.

The computer first generates the "wet" or "dry" status of a day using the conditional probabilities calculated before. If a wet day is generated, it then uses the discrete probability distribution of the amount of rainfall to generate the amount of rainfall in that day.

The procedure to generate daily pan evaporation is similar to that for rain. The only exception is that the observed entire range of pan evaporation values are first categorized in three groups: high values of pan evaporation, medium values and low values. It is then assumed that the "high-medium- or low values" of pan evaporation in a day are dependent on similar status of pan evaporation in previous days. Conditional probabilities of these "high-low- or medium" status are then calculated from similar grouping of past records.

Step 3: Case c: Daily Rainfall and Daily Pan Evaporation Are Independent, and One of Them is Nonrandom while the Other One is Random. In this situation, analysis techniques for the random one is similar to that as described in Case a, while the nonrandom one needs to be treated according to the procedure mentioned in case b.

Step 3: Case d: Both are Random and Correlated to Each Other. In this case, the following alternatives are available:

A discrete probability distribution is first hypothesized for rainfall as described in Case a. For each discretized range of

rainfall, past data on pan evaporation are analyzed to construct a corresponding discrete probability distribution for pan evaporation. The method implied here first generates the amount of rain in a day, and then uses the corresponding pan evaporation distribution to generate the value of pan evaporation.

The other alternative is to hypothesize a continuous or discrete distribution for rain. It is then assumed that amount of pan evaporation on day i is only dependent on rainfall for that day. Past records on daily rainfall and pan evaporation may then be used to perform the regression analysis to evaluate the parameters in the following empirical relationship:

$$PAN_i = f(Rain)_i \qquad [4.44]$$

Once the daily rainfall is generated, the above relationship is then used to estimate the pan evaporation.

Step 3: Case f: Daily Rain and Pan Evaporation are Correlated and Nonrandom. In this case a combination of Case b and Case d are followed.

Step 4: Generating Daily Rainfall and Pan Evaporation for Simulation. Since both rain and pan evaporation are stochastic variables, the simulation process needs to generate random variates either from their empirical tables or from their hypothesized theoretical distributions with desired parameters. This is accomplished by the use of random numbers and Monte Carlo sampling. For this purpose, a computerized simulation model needs to have a means of i) obtaining

uniformly distributed random numbers, and ii) using these random numbers to generate random variates with the desired characteristics (77).

Various packaged subroutines for this purpose are available in most computer facilities. One of the most commonly used of these packaged subroutines is "RANDUM." If the proper parameters are specified, this subroutine can generate lognormal, normal, weibull, exponential, or gamma variates. However, in the case of noninteger α, this subroutine cannot be used for generating gamma variates. However, Phillips (62) has proposed a very versatile two parameter gamma generator that overcomes this problem. The program listing of this subroutine, written in FORTRAN IV, is available in the original publication by Phillips (62).

The Decision Process

Let a decision vector $\vec{d}(c, o, m, n, p, CAP)$ be defined as follows:

$$\vec{d}\,(c, o, m, n, p, CAP) \in (C_c, To, I_m^g, I_n^s, P^p, CAP) \ldots \quad [4.45]$$

where C_c = Collection alternative c; To = Treatment alternative o; $I_m^g = m^{th}$ irrigation technique for irrigating grass; $I_n^s = n^{th}$ irrigation technique for irrigating shade trees; $p^p = p^{th}$ vegetation strategy and CAP = Capacity of the effluent storage facility.

Alternatives in sewage collection, in treatment plants and in irrigation systems for lawns and shade trees are evaluated according to the following decision rule:

$$\text{Maximize } [REV]_d - [COST]_d \quad \ldots \quad \ldots \quad \ldots \quad [4.46]$$

over all d's

where $[REV]_d$ and $[COST]_d$ are the present worth of all benefits and costs associated with $\vec{d}$ respectively.

For any decision vector $\vec{d}$,

$$[REV]_d = \sum_{t=1}^{n_p} \left[\sum_{i=1}^{365} \sum_{q'=1}^{n_{q'}} V^{o,p}_{i,q',t} \; r_{k,q',t} + (LEASE)_t \; (NC)_t \right] \frac{1}{(1+i)} + \frac{(VP)_p}{(1+i)^{n_p}} \qquad [4.47]$$

$$\text{and } [COST]_d = (FC)_c + (FT)^{CAP}_{o,c,m,n} + (FI)^{m,n}_{o,p} + (FI)_p + \sum_{t=1}^{n_p} \left[(OC)_{c,t} + (OT)^{CAP}_{o,c,t} \; (OI)^{m,n}_{p,o,t} + (OP)_{p,t} \right] \frac{1}{(1+i)^t} \; \ldots \; \ldots \qquad [4.48]$$

where n_p = Number of years in the planning period; $n_{q'}$ = number of categories of recreational facilities available with daily permits; $r_{i,q',t}$ = cost of entry permit per visitor on day i, at facility q', in year t; $(LEASE)_t$ = Revenue received per lot for vacation homes in year t; i = interest rate; $(VP)_{n,p}$ = Dollar values of lawn and trees grown in year n_p; $(FC)_c$ = Fixed costs for the collection method c, $(FT)^{CAP}_{o,c,m,n}$ = Fixed costs for the treatment plant o, associated with c^{th} collection system; and m^{th} and n^{th} irrigation techniques for irrigating grass and shade trees with an effluent storage facility of capacity CAP; $(FI)^{m,n}_{o,p}$ = Fixed costs for the irrigation system corresponding to treatment plant o, and vegetation strategy p, and m^{th} and n^{th} irrigation techniques for grass and trees, respectively; (FP) =

Initial costs for planting trees and grass according to the p^{th} vegetation strategy; $(OC)_{c,t}$, $(OT)^{CAP}_{o,c,t}$, $(OI)^{m,n}_{p,o,t}$ and $(OP)_{p,t}$ are the operation and maintenance costs of the collection system, the treatment plant, the irrigation system, and lawns and trees in year t, respectively.

The constraints implied in this model are as follows:

1. BOD, suspended solids, bacteria, and algae contents of the treatment plant effluent to be used for irrigation must meet the regulatory standards, if any, regarding the quality of effluent for the particular disposal or irrigation techniques under consideration. Moreover, the quality of the effluent has to meet the quality required by the associated disposal or irrigation techniques, i.e.,

$$\vec{X}_o \leq \vec{\chi}_{m,r} \qquad [4.49]$$

and

$$\vec{X}_o \leq \vec{Z}_m \qquad [4.50]$$

where $\vec{X}_o \in (BOD_o, SS_o, COLI_o, ALGAE_o)$ ... ... [4.51]

and $\vec{\chi}_{m,r} \in (BOD_{m,r}, SS_{m,r}, COLI_{m,r}, ALGAE_{m,r})$

and $\vec{Z} \in (BOD_m, SS_m, COLI_m, ALGAE_m)$ ... ... [4.52]

where BOD_o, SS_o, $COLI_o$, $ALGAE_o$ are BOD, suspended solids, bacteria and algae contents of effluent from treatment plant o, respectively; $BOD_{o,r}$, $SS_{m,r}$, $COLI_{m,r}$ and $ALGAE_{m,r}$ are the maximum permittable levels of BOD, suspended solids, bacteria and algae contents of effluent by

regulatory standards for m^{th} disposal technique, respectively; and BOD_m, SS_m, $COLI_m$, $ALGAE_m$ are the respective maximum levels of constituents permittable by the m^{th} irrigation technique.

2. The amount of water to be used for irrigation from secondary sources has to be kept within a maximum permittable level depending on the availability and requirements for other beneficial uses. Therefore,

$$\sum_{i=1}^{364} P^{p}_{c,m,n,o,t} \leq (WS)_t \quad \ldots \quad \ldots \quad \ldots \qquad [4.53]$$

where $P_{c,m,n,o,t}$ has been previously defined in Equation [4.35], and $(WS)_t$ is the maximum amount of water from the adjacent lake or groundwater reservoir available in year t.

3. Numbers of lots to be leased for vacation homes are limited by the area of land available for development.

$$(NC)_{nq} \leq (NC)_{max} \quad \ldots \quad \ldots \quad \ldots \qquad [4.54]$$

where $(NC)_{nq}$ = Number of vacation homes at the end of the planning period; and $(NC)_{max}$ is the maximum number of vacation homes which are feasible to be built at the site.

4. Area of land used for irrigation has to be less or equal to the acres of land available for irrigation at the site, i.e.,

$$\sum_{k=1}^{n_k} N^{p}_{j,k} (CANOPY)_k + \sum_{g=1}^{n_g} N^{p}_{j,g} \leq (AREA)_j \quad \ldots \quad \ldots \quad \ldots \quad [4.55]$$

where $(CANOPY)_k$ = Canopy area of k^{th} type tree at maturity; $(AREA)_j$ =

maximum area available on j^{th} soil for irrigation; and other components were previously defined.

CHAPTER 5

IMPLEMENTATION OF THE MODEL

A general framework of the system analysis model was developed in Chapter 4. Although this model is applicable to different recreational areas, some modifications may be required for application to a specific site. The basic purpose of this chapter is to illustrate the use of this model for a specific site. A brief description of the case study area is presented in the first section, and the remainder of the chapter is concerned with development of the procedures to apply the model to the case study area.

The Case Study Area

The study area selected for application of the model to evaluate sewage collection, treatment and irrigation systems is White River Lake, located approximately 45 miles west of Lubbock, Texas. The lake has a surface area of 2400 acres and a capacity of 47,000 acre feet at full lake level. There are approximately 25 miles of shore line.

Primary use of White River Lake is municipal water supply. However, there is a shortage of water-based recreational areas in West Texas and this lake has high potential for recreational development because of its close proximity to a growing metropolitan area. There were about 270,000 daily visitors at the lake in 1974, and 753

annual family use permits were sold for recreational use. The Water District has leased 252 lots for second home development along the lake shore near the dam site.

As determined in a previous soil survey (3), soils represented in current septic tank drainage fields are relatively shallow with low permeability. The drainage fields for the 252 lots generally slope steeply towards the lake. Although no cases of septic tank pollution in the lake have been reported at the present stage of development, there is a potential problem in expanding development of second homes without adopting a central wastewater collection and treatment system.

The adjacent area surrounding White River Lake is currently barren except for scattered mesquite bushes. Day campers are required to use some form of canopy to obtain shade. Previous attempts by the Water District to grow some shade trees by irrigating with lake water has not been successful due to ill planning of the irrigation system and incidents of vandalism.

As indicated in Figure 5.1, the existing water treatment plant is located near the dam site. The site for a central sewage treatment plant as proposed in this study is near the water treatment plant, which is approximately midway in distance from existing lot development on both sides of the lake.

The procedures for modeling various components of the system in White River Lake are discussed in the following sections of this chapter.

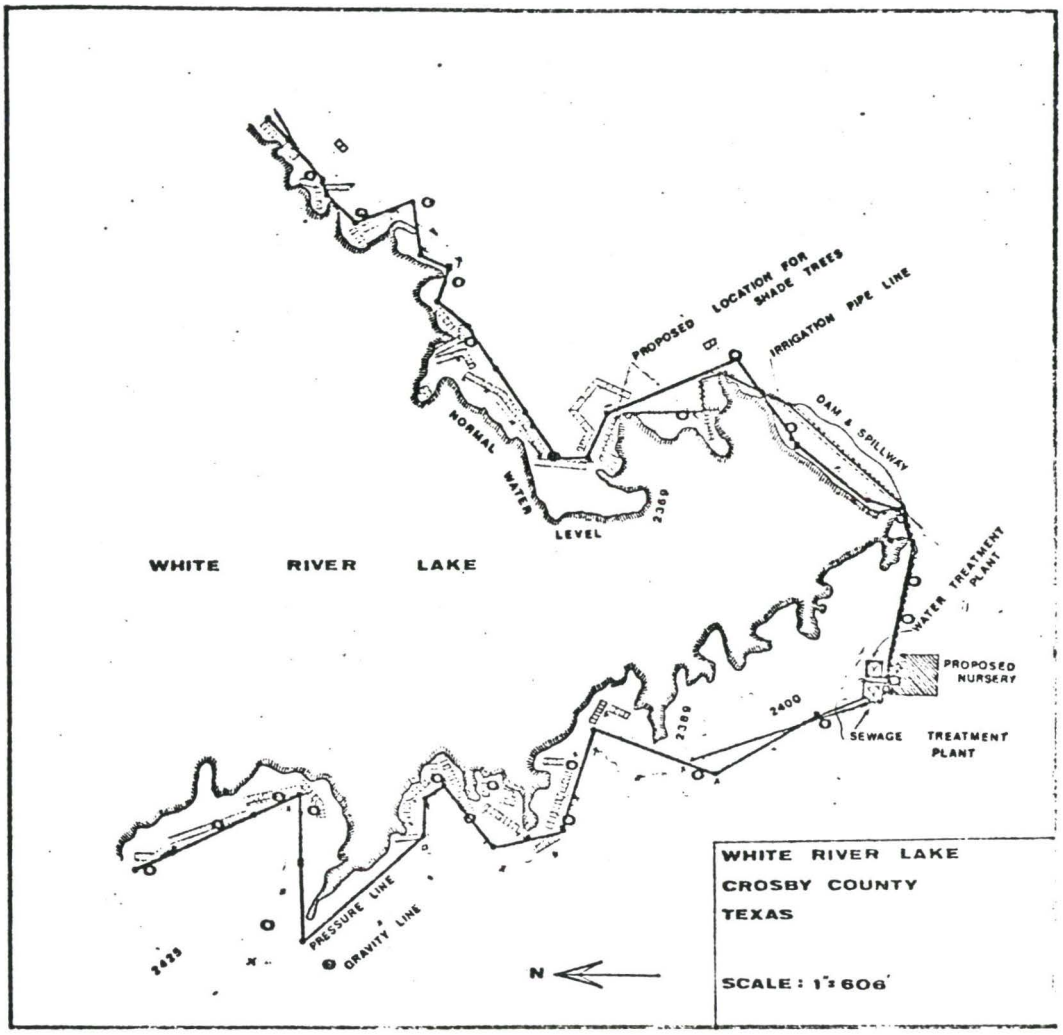

Figure 5.1. Map of White River Lake showing proposed sewage collection system.

Visitation and Volume of Sewage

The recreational facilities available at White River Lake may be divided into two major categories:

Category A: Facilities available on a daily permit basis or annual family use permit such as

i) Camping

ii) Trailer parking

iii) Water ski, fishing and boating

Category B: Facilities available on annual lease, such provision of lot spaces as for

i) Vacation homes

Visitation at the facilities for Category A has been projected on the basis of known permit sales from 1969 to 1974. The following linear model was employed to project the rate of growth in annual permit sale for Category A:

$$P_t^A = 70{,}360 + 2{,}756 \qquad (R^2 = .92) \qquad [5.1]$$

where P_t^A = Projected number of permit sales at the facilities for Category A in year t, estimated from past records of permit sales.

$X_t = t - 1969$, where 1969 is the base year

As P_t^A is estimated from past records of permit sales for use of facilities by Category A, this value does not include nonpaying visitors. The current policy at White River Lake is that all children and local residents of the Water District are not required to purchase permits. Annual visitation for Category A is estimated as

a linear function of Annual permit sales.[a]

$$V_t^A = 3.0\ P_t^A \qquad [5.2]$$

where V_t^A = Total visitation in year t at the Facilities for Category A

Total visitation at the facilities for Category B involving vacation home owners in year t is estimated as follows:[b]

$$V_t^B = 30.0\ *(NC)_t \qquad [5.3]$$

where V_t^B = Total visitation at the facilities of Category B, in year t

and $(NC)_t$ = Number of lots leased for vacation homes in year t

In using Equation 5.3, it is assumed that there are three persons per family leasing the vacation homes, and that each family visits the site ten times per year on the average.[c]

If the rate of increase in visitation to facilities for Category A is not influenced by increased attractiveness of the site, the projected total visitation at the lake in year t is:

$$V_t = V_t^A + V_t^B$$

$$= 3.0\ (70{,}360 + 2{,}756\ X_t) + 30.0\ (NC)_t \qquad [5.4]$$

---

[a] Source: Interviews in person with Mr. O'Brien, Chief Engineer, White River Lake, Texas.

[b] Ibid.

[c] Ibid.

This projected visitation and also the number of lots leased for vacation home development at White River Lake are assumed to increase at an accelerated rate with proposed central treatment plant and irrigation facilities.

Installation of a central sewage treatment plant would allow further vacation home development with less danger of potential lake pollution. The proposed improvement in recreational value stemming from planting shade trees in camping areas should promote more visitation. Reliable data were not available for this study to project the actual increases in visitation and in vacation home development relative to potential improvement alternative for the facilities. The analysis is, therefore, limited to evaluating the costs and benefits of improving the existing sewage collection and treatment facilities and irrigating shade trees with treated effluent under different assumed projections for increased visitation. Thus, values of $\nu_{o,p}$ in Equasion [4.4] cannot be quantified directly for the case study area. Alternative increased rates of growth in visitation are assumed for each combination of treatment and disposal alternatives to estimate the economic benefits of selecting a conjunctive sewer treatment and disposal plan for White River Lake.

Past records of total permit sales in each month from 1969 to 1974 were used to determine the monthly fluctuating pattern of visitation in a year. Figure 5.2 shows the percentage distribution of annual visitation in different months. Figure 5.3 shows the distribution of total visitors in each month using the camping facilities.

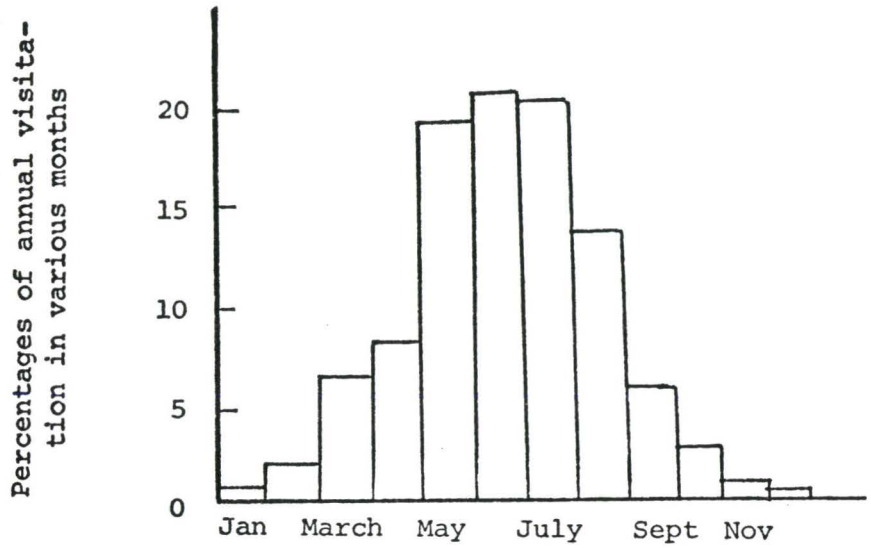

Figure 5.2. Percentages of annual visitation in various months at White River Lake, Texas.[a]

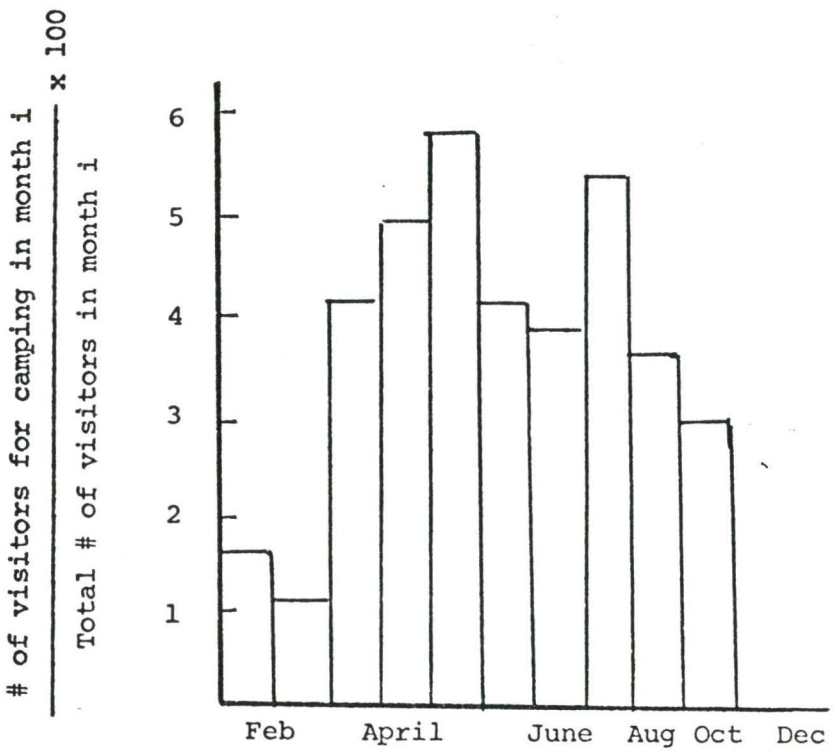

Figure 5.3. Percentages of total monthly visitors using the camping facilities in corresponding months at White River Lake, Texas.

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[a]Both monthly and annual visitation considered here are the visitation at the facilities for Category A.

No specific past records were available on the number of visitors using trailor parking facilities at White River Lake. One percent of the total visitors in each month for Category A was assumed to use trailer part facilities (93). Table 5.1 shows estimated visitor activity values for calculating $b_{q,i}$ values in Equasion [4.5]. Visitation is influenced by rainfall if evaluated on a daily basis. It is assumed that daily visitation is reduced if rainfall occurs as indicated by Equasion [4.7] in Chapter 4. Daily visitations at various sites, as shown in Table 4.7 could be used to calculate the volume of sewage. In the case of gravity collection, a maximum infiltration rate of 1500 gallons per mile of collection line for 1.2 inches of daily rain was assumed. For the pressure collection method, infiltration was assumed to be zero.

Collection System Costs

Installation cost for the sewage collection system is directly dependent on the proposed rate of development of various facilities at the site through the planning period. Increased activity is expected to result from adopting a central sewage treatment plant to allow further vacation homes development and because of the proposed improvement in recreational value stemming from planting shade trees. In order to evaluate the economics of employing alternative sewage collection-treatment and disposal methods, one of the basic requirements for the computer simulation program was to estimate the cost of alternative collection systems associated with different assumed rates

TABLE 5.1

ESTIMATED AND ASSUMED VALUES OF VARIOUS PARAMETERS USED TO CALCULATE VISITATION COEFFICIENT, $b_{q,i}$

Month	Precent of Annual Visitation b	Percent of total visitors in a month using the camping facilities in corresponding month. b	Percent of total visitors in a month using the trailor connection facilities in corresponding month. c	Precent of total visitors in a month using the boating, fishing or sight seeing facilities. d	Precent of total visitors in a month coming in all the weekends of that month. c	Precent of total visitors in a month coming in all the weekdays of that month. c
January	1.03	1.82	1.00	97.18	73.00	27.00
February	2.00	1.04	1.00	97.96	73.00	27.00
March	6.42	4.05	1.00	94.95	73.00	27.00
April	8.63	4.83	1.00	94.17	67.00	33.00
May	18.87	5.79	1.00	93.21	67.00	33.00
June	20.12	3.97	1.00	95.05	67.00	33.00
July	19.85	3.71	1.00	95.29	67.00	33.00
August	13.54	4.24	1.00	94.76	67.00	33.00
September	5.63	3.50	1.00	95.50	67.00	33.00
Oct.	2.92	2.78	1.00	96.22	70.00	30.00
Nov.	0.67	0.00	1.00	99.00	70.00	30.00
Dec.	0.32	0.00	1.00	99.00	70.00	30.00

[a]All vistation shown in this table are the visitation to the facilities for catagory A.

[b]Estimated from past records of permit sales from 1969 to 1974 at White River Lake, Texas.

[c]Source: U.S. Department of Army (1969).

[d]Calculated from column 3 and column 4.

of development of facilities at the site. Both pressure and gravity collection systems were designed for fifteen different assumed levels of development at the site over the period 1975-1974. Costs associated with these designs were then used to formulate appropriate cost equations for estimating collection costs at any rate of development. Various assumed rates of development, for which the collection systems were designed, are shown in Table 5.2. Major assumptions used in designing the systems at these levels were:

Assumption Set A

(1) Additional vacation homes, if any, would be located adjacent to the existing developments, preferably along both sides of the sewer main shown in Figure 5.1.

(2) In the case of pressure sewers, additional vacation homes would be so located that each grinder pump can service five homes.

(3) Any further increase in visitation for visitor Category A, due to the provision of shade trees would be concentrated at the irrigated areas. Therefore, the sewage from additional daily visitors would be generated in visitor's rest rooms number 1 and 2, which are close to the proposed irrigated areas (Figure 5.1). Sewage loads at the two other visitors's rest rooms would not be affected by any such increase in daily visitation.

(4) The main sewer lane and boosting stations or lift stations would be initially designed for maximum estimated daily peak flow through the entire planning period. Only the laterals and additional manholes would be installed during the development period with additional loading.

(5) Regardless of the change in development of vacation homes and/or campgrounds, there would be no further increase in the number of employee's apartments, office buildings, restaurants or gas stations located at the site.

TABLE 5.2

ALTERNATIVE PROJECTIONS OF THE RATE OF INCREASE IN VACATION HOMES DEVELOPMENT AND DAILY VISITATION WITH ASSOCIATED COSTS FOR ALTERNATIVE COLLECTION SYSTEMS, WHITE RIVER LAKE, TEXAS 1975

Design Number	Number of Vacation homes in 1994	Assumed trend in development of further vacation homes	Percent increase in visitation at the Facilities of Category A; above the visitation as predicted by Equation (4.2)	Total Installation Costs $		Comment
				Pressure System	Gravity System	
A - i	252	No Futher	0.0	214382.		All estimated costs are subject to Assumption Set A
A - ii	252	Vacation homes	80.0	228507.	272915.	
A - iii	252		160.0	242634.		
B - i	352	Connection to	0.0	252022.		
B - ii	352	5 new homes	80.0	266147.	301565.	
B - iii	352	each year	160.0	280274.		
C - i	452	Connection to	0.0	289662.		
C - ii	452	10 new homes	80.0	303787.	330215.	
C - iii	452	each year	160.0	317914.		
D - i	552	Connection to	0.0	327302.		
D - ii	552	15 new homes	80.0	341427.	358865.	
D - iii	552	each year	160.0	355554.		
E - i	652	Connection to	0.0	364942.		
E - ii	652	20 new homes	80.0	379067.	387515.	
E - iii	652	each year	160.0	393194		

Both pressure collection and gravity collection systems were designed for alternative levels of projected development based on Assumption Set A. Figure 5.1 shows the proposed sewer line layouts for the alternative collection connecting the existing facilities. Design and cost estimating procedures used for pressure and gravity collections are discussed in the subsequent sections.

Pressure Collection

The topography and dispersion of different sources of sewage in the development area were considered in determining the most economic location for the grinder pumps. Each grinder pump was located to serve three or more homes. Sewage from these sources was first collected by a 4 inch gravity flow pipe at the location of the grinder pump. Each grinding unit was assumed to be a 1½ HP-230V simplex-type submersible grinder pump equipped with 0.25 inches thick steel tank, two feet in diameter and five feet deep with gas tight cover. As the public rest rooms are major sources of sewage, generating more than 50 percent of total daily sewage flow, two simplex-type grinder pumps were allocated to each of the four public rest rooms in design A-i, B-i, C-i, D-i and E-i. For designing the collection systems of A-ii, B-ii, C-ii, D-ii and E-ii, as shown in Table 5.2, two of the public rest rooms close to irrigation sites were each provided with one simplex-type and one duplex-type grinding units. Two duplex-type grinder pumps were allocated to each of these two public rest rooms for design number A-iii, B-iii, C-iii, D-iii and E-iii. The performance curves for these pumps and the complete hydraulic analysis and

life schedules for design number A-i are shown in Appendix
Various components of installation cost for the collection system are also shown in Appendix

Maximum daily peak flow in the planning period corresponding to alternative development rates shown in Table 5.2 were used to determine the diameter to the main sewer in each design. Maximum daily peak flow along any section of the main sewer was determined on the basis of the maximum number of grinder pumps working simultaneously in the section under consideration (6). The maximum system pressure was kept within 70 feet of water head. Each of the grinding units was capable of delivering about 10 gallons of wastewater per minute against this maximum head. In cases where total head loss for any pump exceeds 60 feet, a boosting station is installed on the sewer main.

Additional lateral pipe lines, grinder pumps and valve boxes to serve the new vacation homes, if any, were assumed to be installed annually along with the assumed development of vacation homes. Present worth of the annual costs for further installation of laterals and grinder pumps was considered in evaluating the total installation cost for the collection systems in design numbers (B-C-D-E: i-ii-iii).

The estimated installation costs for pressure sewers at various rates of development are shown in Table 5.2. In Figure 5.4 these costs are related to the number of vacation homes in 1994 at the three different rates of development in daily recreational facilities. The additional costs for a collection system corresponding to

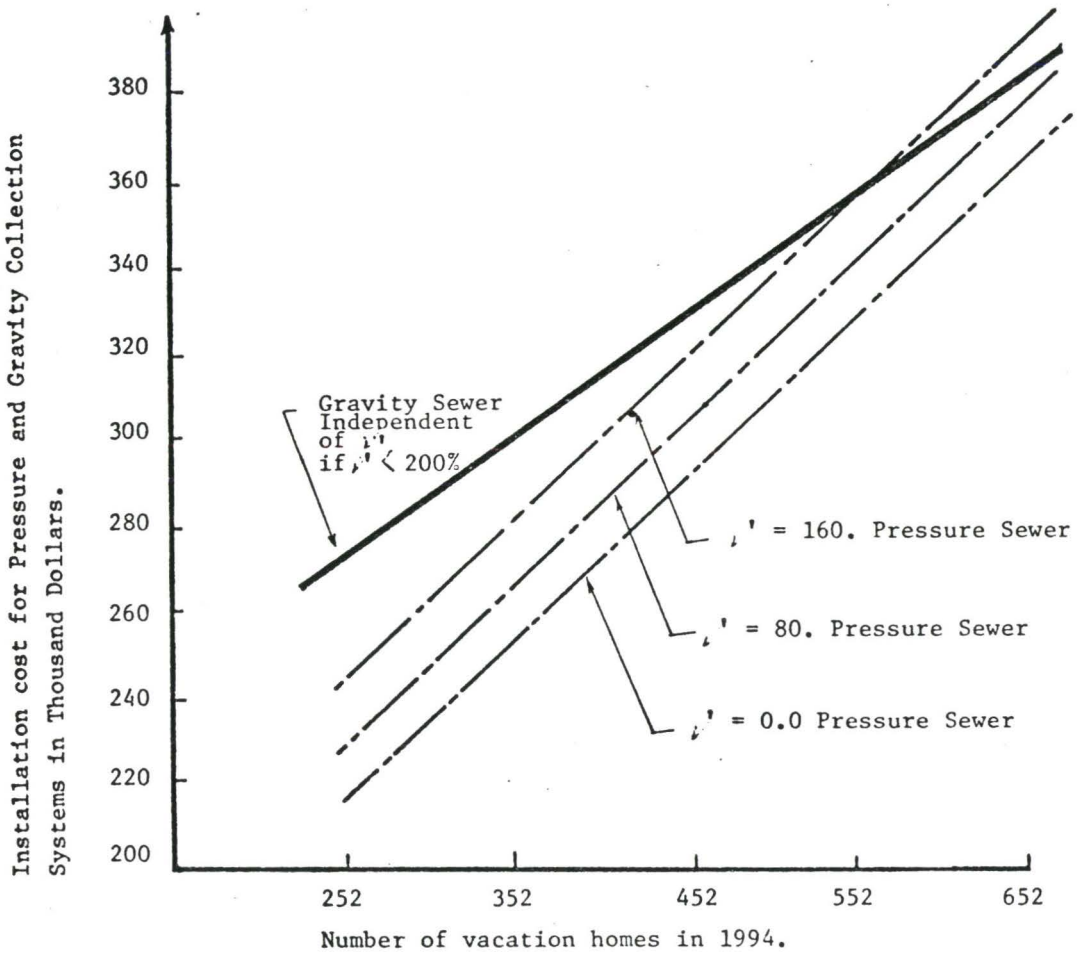

Figure 5.4. Relationship between the number of vacation homes projected by 1994 and installation costs for pressure collection and gravity flow collection systems with alternative increased rates of growth in daily visitation.

increased visitation at the facilities for visitor category A are due to the installation of duplex grinder pumps instead of simplex pumps at public rest room numbers 1 and 2, and due to increase in main sewer diameter for service to these facilities. The additional costs of the collection system for further development of vacation homes are due to the periodic additional installation of lateral pipes, grinder pumps and valve boxes. Since all the cost functions in Figure 5.4 are linear, and since each of them is parallel to each other, these can be represented by a general equation as follows:

$$IC_{\nu',P} = (119529.2 + 176\ \nu') + 376.4\ (NC)_{1994} \qquad [5.5]$$

where $IC_{,p}$ = Installation cost of pressure sewer collection system for service to a development rate denoted by ν' and $(NC)_{1994}$

ν' = Percent increase in daily visitation attributed to improved quality of facilities at the site above the estimated visitation evaluated by equasion [5.2]

$(NC)_{1994}$ = Total number of vacation homes in 1994.

Gravity Collection

Laterals and minor sewers were designed for a peak load of four times the average daily flow (85). The main trunk was designed for a peak capacity of 2.5 times the average daily flow. However, for all the design situations listed in Table 5.2, the minimum size of

the laterals and trunk sewers was less than the minimum acceptable sizes as required by the regulations of the Texas State Department of Health (85). Therefore, the laterals and trunk sewers for all designs were increased to four inch and six inch diameter pipes, respectively. All the specific assumptions listed formerly as "Assumption Set A" were applied to the gravity sewer design for further development of recreational facilities. The laterals and main lines were assumed to be installed at a continuous slope of .006 feet per foot up to a maximum depth of twelve feet to sixteen feet below the ground surface. Lift stations are assumed to be provided to avoid excavation beyond sixteen feet. The capacities of lift stations range from 40 gpm to 80 gpm depending on their relative location on the trunk sewer and the rate of development of further vacation homes. All other relevant design considerations regarding the depths of various sections of main line and the proposed location of lift stations at both sides of White River Lake are discussed in Appendix Components of installation cost for a gravity system corresponding to these designs are also documented in Appendix

As mentioned previously, the minimum size of the laterals from public rest rooms number 1 and 2, and the minimum size of the main sewer for these facilities need to be at least four inches and six inches respectively due to state regulations. The main line is sufficiently large to accommodate any increased sewage flow generated in these rest rooms with further increases in visitation over the twenty-year planning period. The laterals connecting the rest rooms to the

main line may be increased from four inches to six inches with additional loading at a relatively low cost. As this is the only additional cost for gravity flow facilities, the total installation cost for a gravity system increases very little with increasing visitations at the facilities of Category A. However, additional lateral pipe lines and manholes would be required.

Installation costs of gravity collection systems at different projected rates of development are shown in Table 5.2. These cost figures are related to the projected number of vacation homes in 1994 in Figure 5.4. The mathematical expression for the gravity collection system cost function is defined as:

$$IC_g = 200717.0 + 286.5\ (NC)_{1994} \qquad [5.6]$$

where IC_g = Installation cost for a gravity system.

Treatment Alternatives

Wastewater disposal standards and the quality of effluent needed for associated irrigation methods limit the choice of treatment alternatives as follows:[a,b]

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[a]The effluent disposal standards in Texas area are: i) Maximum permittable BOD in effluent = 20 mg/liter, ii) Maximum permittable suspended solids = 20 mg/liter, iii) Total fecal coliform count must be less than 200 on monthly average. Sources of these data are Mr. William Mays and Mr. Ray Mittel, Texas Water Quality Board, Lubbock, Texas.

[b]Suggestions and recommendations from the following professionals have been considered while selecting the treatment alternatives: i) Mr. Cecil Hawks, Consulting Engineer, Hicks and Raglands,

(1) Primary treatment and stabilization pond: applicable to sprinkler irrigation or no irrigation.

(2) Any secondary treatment plant: applicable to straight disposal without irrigation.

(3) Standard rate trickling filter plant + storage: applicable to sprinkler irrigation.

(4) High rate trickling filter plant + storage: applicable to sprinkler irrigation.

(5) Activated sludge plant + storage: applicable to sprinkler irrigation

(6) Package plant + storage: applicable to sprinkler irrigation

(7) Standard rate trickling filter plant + stabilization pond + storage: applicable to submatic irrigation

(8) High rate trickling filter plant + stabilization pond + storage: applicable to submatic irrigation.

(9) Activated sludge plant + stabilization pond + storage: applicable to submatic irrigation.

(10) Package plant + stabilization pond + storage: applicable to submatic irrigation.

Total construction costs as well as operating and maintenance costs were estimated from eight principal sources.[a] In some

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Lubbock, Texas; ii) Dr. Sewagy, Department of CE, Texas Tech University; iii) Mr. Dale Brown, Submatic Inc., Lubbock, Texas; iv) Mr. Tom Scarborough, Tom's Tree Place, Lubbock, Texas; v) Mr. Ray Mittel, Texas Water Quality Board, Lubbock, Texas. According to these recommendations a storage is necessary for efficient planning of the irrigation systems and a stabilization pond is required for further separation of solid matters to reduce the clogging of the emitters in case of submatic irrigation. Further filtration of effluent through manually cleaned strainers and self flushing sand filters are provided in the submatic system.

[a]The sources are: Shah and Reid (79), Logan et al, (49), Michel (56), Lamp (47), Smith (80), Smith et al. (80), and Quasim (64).

instances, estimated costs by various methods vary widely. Therefore, the average values of construction or operating and maintenance costs as estimated by these alternative cost estimating equations were used in this study.[a] Construction costs reported by Logan et al. (49) or Shah and Reid (1970) exclude ancillary works and preliminary expenses such as engineering and legal fees, interest during construction, etc. In these instances, the estimated cost were increased by 20 percent to include these ancilliary and preliminary expenses (80). Various cost estimating equations used in this study are shown in Appendix

As most of the cost estimating equations are based on past cost records of various sewage treatment plants in the U.S.A., these were assumed to be valid for average design characteristics and performances. No studies, except those reported by Logan et al. (49) and Quasim (64) show any breakdown of construction or operation costs. Operation and maintenance costs estimated from these sources include chlorination cost based on average performance characteristics. But as chlorination costs in this study are directly dependent on the disposal alternatives, operation and maintenance costs estimated from these sources were first adjusted to exclude the chlorination cost.[b] Along with the operation and maintenance costs of the

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[a] To take the average of the cost estimated from various sources is not uncommon for treatment plant planning. Smith (80) used a similar approach while discussing various cost estimating procedures.

[b] Chlorination costs based on average performance have been first estimated by Logan et al.'s (49) method. These estimates have been used to adjust the O&M costs.

treatment plants, chlorination costs were calculated separately to account for the dosage of chlorine required by various disposal alternatives.

WPC-STP indexes were used to adjust the estimated construction cost to December 1974 for Texas. U.S. Department of Labor Average Earnings for nonsupervisory workers in water, steam and sanitary systems were used to adjust the operation costs to December 1974. Estimated construction and operation and maintenance costs of various treatment plants are shown in Table 5.3. Contact stabilization and extended aeration type package plants were estimated to have comparable costs and were, therefore, combined in Table 5.3. Relative costs of different treatment plants are illustrated in Figure 5.5 and 5.6.

Irrigation System Cost

Various irrigation alternatives considered for the case study area are i) automated solid set sprinkler (40' x 40' spacing), ii) automated submatic irrigation (40' x 40' spacing, 2 emitters per tree and iii) automated submatic irrigation with 5' x 5' spacing to irrigate grass lawns.

Since a stabilization pond provides ideal conditions for algae growth, sufficient filtration of the effluent is needed for submatic irrigation. Therefore, the filtration system for submatic irrigation was designed to include i) two 2-wire per mm stainless steel mesh screens, ii) an automatic backwashing sand filter unit, iii) a series of sand cartridge filters and iv) a strainer with 100 mesh

TABLE 5.3

AVERAGE CONSTRUCTION, OPERATION AND MAINTENANCE COST OF SEWAGE TREATMENT PLANTS ALTERNATIVE LOADING RATES

	Design Capacity of the Plant (Mgd)							
	.076		.203		1.0		10.0	
	Const. Cost $1000/ Mgd a	O & M Cost Thousand dollars/ Mgd a	Const. Cost Thousand dollars/ Mgd a	O & M Cost Thousand dollars/ Mgd a	Const. Cost Thousand dollars/ Mgd a	O & M Cost Thousand dollars/ Mgd a	Const. Cost Thousand dollars/ Mgd a	O & M Cost Thousand dollars/ Mgd a
Primary d	350.4	36.5	326.9	22.7	203.1	10.95	12.1	3.85
Stabilization Pond f	531.5	18.0	349.8	11.2	235.8	5.4	9.97	1.90
HRTF Plant d	1334.5	82.7	992.1	58.3	713.1	34.5	41.2	16.2
SRTF Plant d,	1663.6	79.4	1192.8	56.7	787.5	32.6	39.8	15.6
Activated Sludge d	1866.0	99.5	1458.7	72.4	1016.2	49.7	59.4	27.5
Package Plant b	903.6	99.2	643.16	57.2	430.7	30.1	n.a c	n.a.c.

[a]Construction cost estimates are for December 1974 and are based on the WPC-STP index for Dallas, Texas; 198.24. Operation and maintenance costs are for December 1974 and are based on U.S. Department of Labor Average Earnings for non-supervisory workers in water, stream and sanitary systems.

[b]Construction costs were estimated by a method reported by G.E. Lamp (1974). Operation and maintenance costs were estimated by a method reported by S.R. Qasim and A.K. Shah (1975). Data were also obtained from Hicks and Ragland (Consulting Engineers), Lubbock, Texas and from various manufacturers or distributors of package plant equipment.

[c]Not applicable.

TABLE 5.3--Continued

[d] Based on methods by Shah and Reid (1970) Logan et.al. (1962) and R.L. Michael (1970).

[e] Based on methods reported by Shah and Reid (1970), Logan et.al. (1962), U.S. Department of Health and Welfare (1964), and R.L. Michael (1970).

[f] Based on methods reported by Shah and Reid (1970), U.S. Department of Health and Welfare (1964) and R.L. Michael (1970)

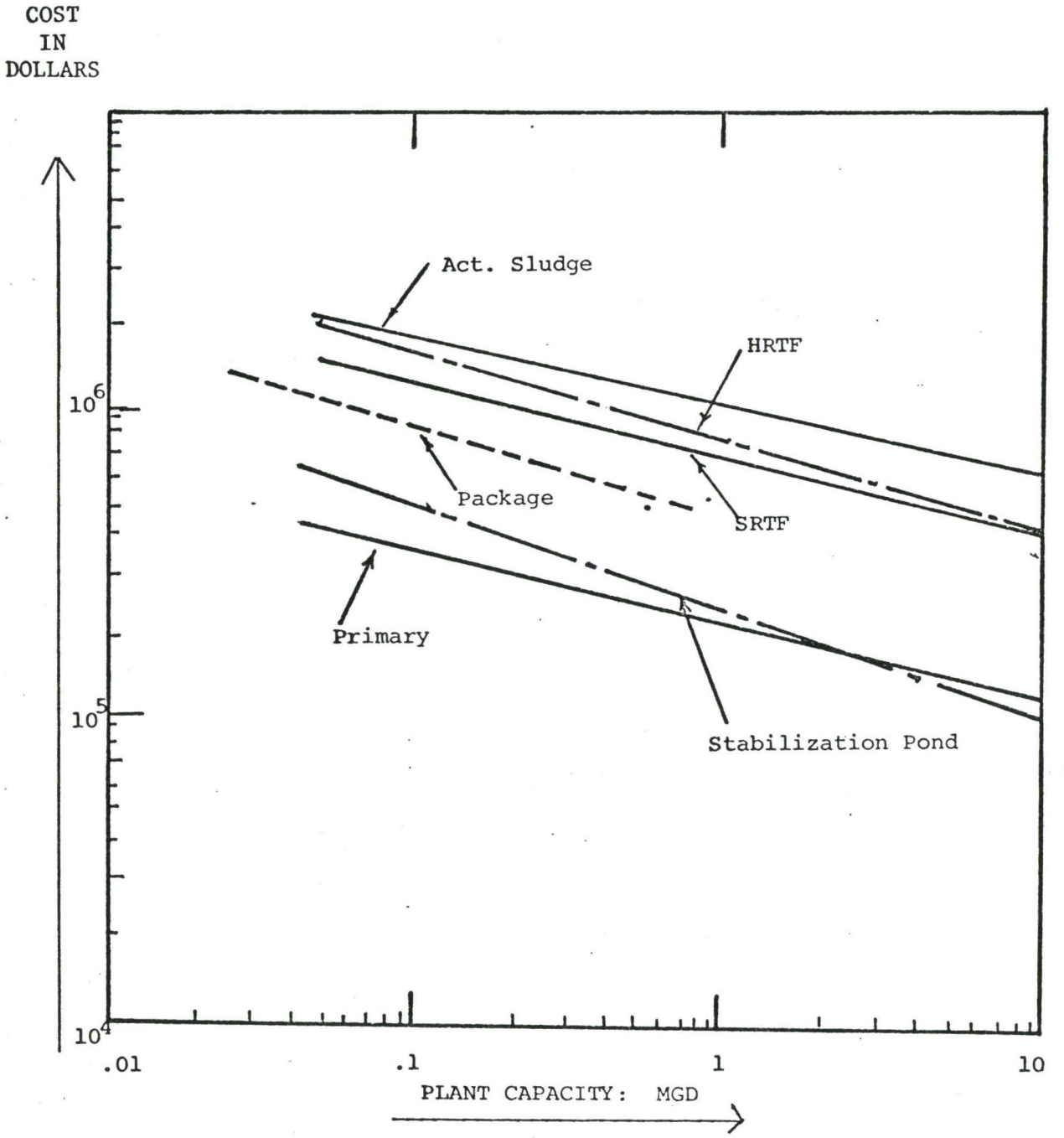

Figure 5.5. Construction cost per mgd for different treatment alternatives at White River Lake, Texas, December 1974.

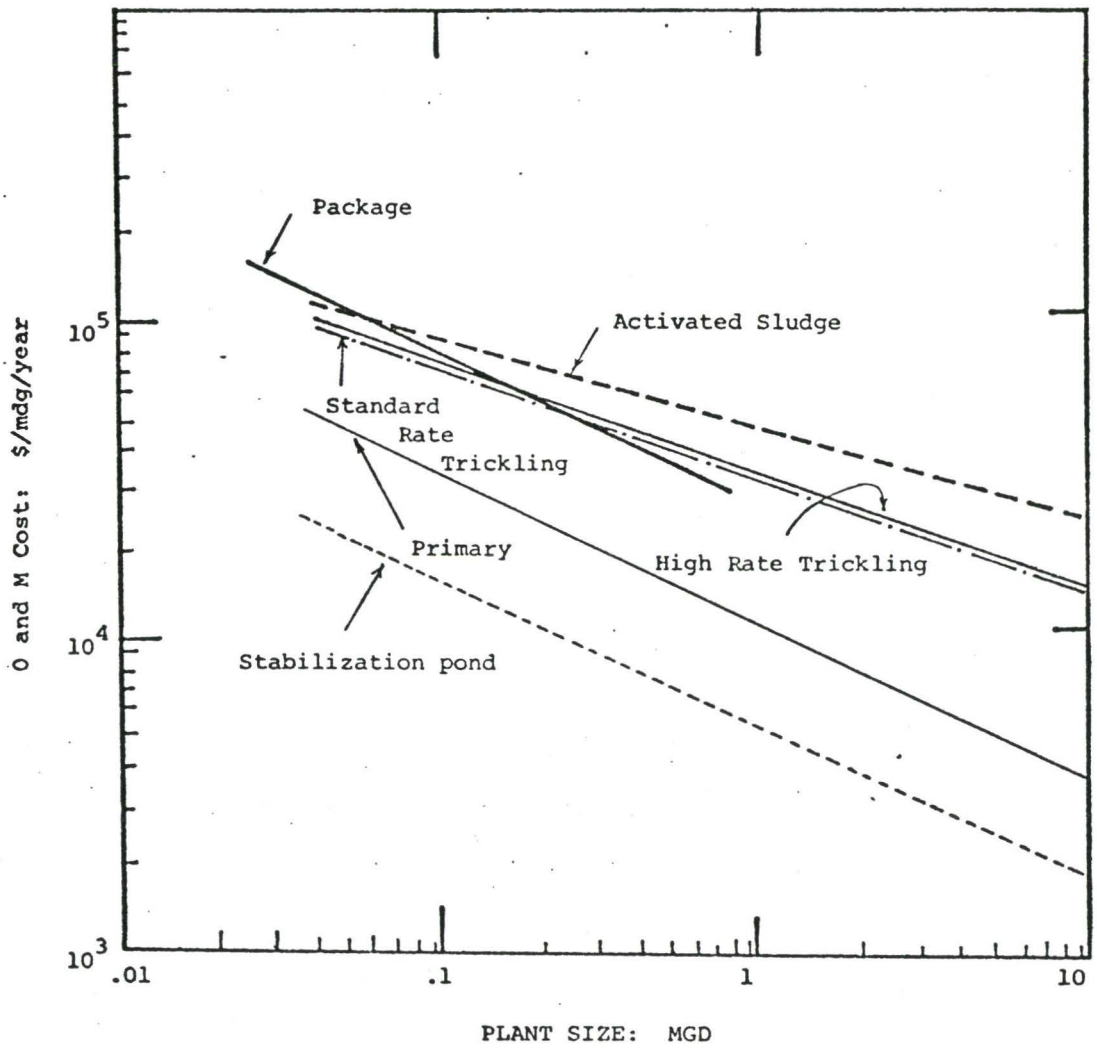

Figure 5.6. Operation and maintenance costs per Mgd for different plants at White River Lake, Texas, December 1974.

stainless steel.[a] The flow diagram for the filtering units are shown in Figure 5.7. The screen filters located at the offtake sump need to be cleaned manually with a high pressure jet. The cleaning operation was assumed to take 20 minutes a day.

Installation costs for various alternative irrigation systems are shown in Table 5.4 and Figure 5.8. Components of these installation costs are shown in Appendix

Since operation and maintenance costs of the irrigation system are dependent on rainfall, pan evaporation, number of trees to be grown, etc., these are basic inputs to the simulation model. The cost figures and assumptions used for estimating the operation and maintenance costs of the irrigation system are listed in the discussion of the output of the computerized simulation model in the subsequent chapter.

Soil Moisture Balance

Soil characteristics over much of the site area at White River Lake are not suitable for any kind of shade trees. Physical properties of soils at four selected irrigation sites are shown in Table 5.5. These sites were selected on the basis of their more favorable soil characteristics and their proximity to the wastewater treatment plant. One of these four irrigation sites is an existing campground on the

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[a]References for the irrigation system design are: Interviews in person with Mr. Dale Brown, Submatic Inc., Lubbock Texas; Mr. Tom Scarborough, Tom's Tree Place, Lubbock, Texas; and Read and Pietsch (67).

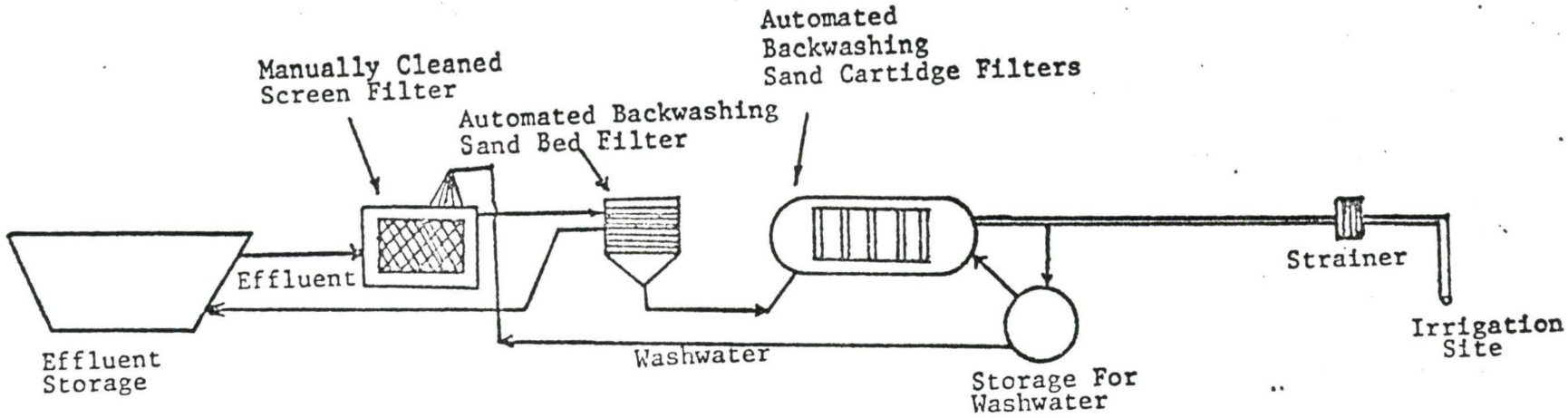

Figure 5.7. Filtering components in submatic irrigation.

TABLE 5.4

INSTALLATION COSTS FOR SOLID-SET SPRINKLER AND SUBMATIC IRRIGATION SYSTEM, WHITE RIVER LAKE, TEXAS[a]

Irrigation Techniques	Total Area Irrigated (Acres)								Equation for Total Cost
	5		10		20		40		
	Total Cost ($)	Cost/Acre ($/Acre)	Total Cost ($)	Cost/Acre ($/Acre)	Total Cost ($)	Cost/Acre ($/Acre)	Total Cost ($)	Cost/Acre ($/Acre)	($)
Sprinkler: solid set: automated: 40' x 40' spacing	8807.	1761.4	15619.	1562.	30242.	1512	58500.	1462.5	Total Cost=14198 (Area Irrigated) + 1708.
Sprinkler: Solid set: Manual: 40' x 40'	5400.	1080.	9305.	931.	b		b		Total Cost=781 (Area Irrigated) + 1495.
Submatic: automated 40' x 40' spacing:	6450.	1290.	b		10330.	517	14300.	358	Total Cost=242 (Area Irrigated) + 5328
Submatic: automated 5' x 5' spacing	10350.	2070.	b		24600.	1232	40300.	1008	Total Cost=855.7 (Area Irrigated) + 6071.4

[a]The cost for pipe connecting the effluent storage and the supply point to the irrigation site is not included. The estimate includes costs for laterals, submains, pumps & motors, filtering and flushing systems, storage for washwater, proportioner and control stations along with other costs for electric connections, filtering & housing; Sources for various cost figures: Redi Rain Inc., Lubbock: Submatic Inc., Lubbock, Yardney Corp. Corona, California; Plastiline Inc., Pompano Beach, Florida; Amoco Chemicals Corp. Wichita Falls, Texas.

[b]Not evaluated.

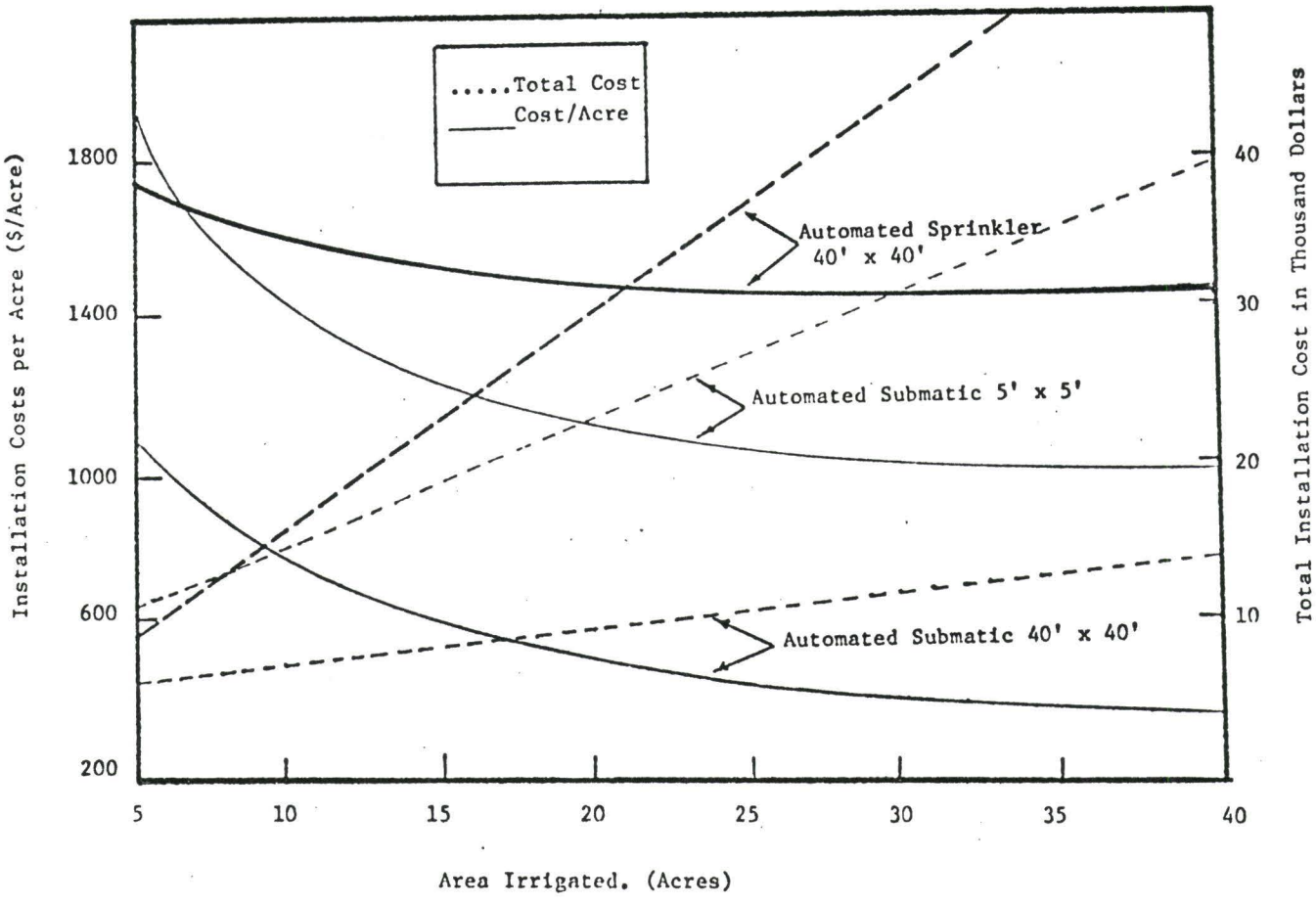

Figure 5.8. Installation costs of irrigation systems at White River Lake, Texas.

TABLE 5.5

SOIL PROPERTIES AT VARIOUS PROPOSED IRRIGATION SITES, WHITE RIVER LAKE, TEXAS

Proposed Irrigation Site Number	Soil Name a	Major Soil Horizons (inches) a	Soil Classification (USDA Texture)	Field Capacity in/in b	Available Water Capacity in/in b
1,3 and 5	Miles Fine Sandy Loam	0 - 10"	Fine sandy loam	.15	.11
		10 - 70"	Sandy Clay loam	.17	.13
2	Berda Loam	0 - 60"	Loam or Clay loam	.17	.14
4	Latom Polar Complex c/	0 - 7"	Gravelly sandy loam	.09	.04
		7 - 60"	Very gravelly sandy loam	.07	.03

[a]Source: Blackstock and Neitsch (1972).

[b]Source: Telephone conversation with Mr. Dan Blackstock, co-author, Blackstock and Neitsch (1972).

[c]Only Polar part of the soil is suitable for shade trees. The depth to rock in the Latom part is not sufficient enough to allow root growth of a tree.

east side of the lake, which has the first priority for a irrigation development.

Various types of shade trees which are adaptable to the soils of the selected irrigation sites were categorized into three groups according to their respective canopy growth rates. Table 5.6 shows these classification of tree varieties.

As the consumptive use of a tree depends on the growth stage, the rate of growth of various trees needs to be estimated to determine irrigation application requirements over the planning period. The trunk diameters and canopy sizes of the trees, irrespective of soils on which they are grown, were assumed to increase at a constant rate each year. The assumed values for canopy sizes and trunk diameters of various categories of trees are shown in Table 5.7. These figures were obtained from local irrigation and horticulture experts.[a] Mortality rates for all types of shade trees were assumed to be 36, 24 and 12 percent in the first, second and third year after planting, respectively (82). All dead trees were assumed to be replaced by a new tree of equivalent age. Mortality rates after the third year of establishment were assumed to be zero.

Experimental results of previous studies of orchards were used to estimate the consumptive use of shade trees.[b] Due to insufficient

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[a]Source: Dr. George Elle, Department of Horticulture, Texas Tech University, Lubbock, Texas; Mr. Dale Brown, Submatic Inc., Lubbock, Texas; Mr. Tom Scarborough, Tom's Tree Place, Lubbock, Texas; and Blackstock and Neitsch (3).

[b]Source: Keese and New (42), and Zetzsche and Newman (116).

TABLE 5.6

CLASSIFICATION OF TREES ACCORDING TO CANOPY SIZES AT MATURITY

Category	Approximate Canopy Canopy Size after 20 years of growth, irrigated. [a]	Major purposes [b]	Species which are adaptable to local soils. [b]
A	15 ft. radius	Shade	Russion Olive Honey Locust Hackberry Chinese Elm
B	10 ft. radius	Shade and/or screen	Murlberry Rocky mountain junipar Austrian Pine
C	6 ft. radius	screen and/or beautification	Oriental Arbivitae Desert Willow

[a]Source: Dr. George Elle, Department of Horticulture, Texas Tech University, Lubbock, Texas.

[b]Source: Blackstock and Neitsch (1972).

TABLE 5.7

ESTIMATED ANNUAL GROWTH OF SHADE TREES IN TRUNK DIAMETER AND CANOPY SIZE[a]

Year	Radius of Canopy (Feet)			Trunk Diameter (Inches)			Mortality Rate
	Tree Category			Tree Category			(Percent)
	1	2	3	1	2	3	b
1	1.0	1.0	1.0	1.0	1.0	1.0	36
2	1.74	1.48	1.26	1.52	1.31	1.15	24
3	2.47	1.94	1.52	2.05	1.63	1.31	12
4	3.21	2.42	1.78	2.57	1.94	1.47	0
5	3.95	2.89	2.05	3.10	2.26	1.63	0
6	4.68	3.36	2.31	3.63	2.57	1.78	0
7	5.42	3.84	2.57	4.15	2.89	1.94	0
8	6.16	4.31	2.84	4.68	3.21	2.10	0
9	6.89	4.78	3.10	5.21	3.52	2.26	0
10	7.63	5.26	3.36	5.73	3.84	2.42	0
11	8.36	5.73	3.63	6.26	4.15	2.57	0
12	9.10	6.21	3.89	6.78	4.47	2.73	0
13	9.84	6.68	4.15	7.31	4.78	2.89	0
14	10.58	7.15	4.42	7.84	5.10	3.05	0
15	11.32	7.63	4.68	8.36	5.42	3.21	0
16	12.05	8.10	4.94	8.89	5.73	3.36	0
17	12.79	8.57	5.21	9.42	6.05	3.52	0
18	13.52	9.05	5.47	9.94	6.36	3.68	0
19	14.26	9.52	5.73	10.47	6.68	3.84	0
20	15.0	10.0	6.0	11.00	7.00	4.00	0

[a]Sources: Dr. George Elle, Dept. of Horticulture, Texas Tech. Univ. Mr. Brown, Submatic Inc., Lubbock, Texas. Redi Rain Inc., Lubbock, Texas.

[b]Sources: Sopper and Kardos (1973)

data, comsumptive use coefficients for the trees were assumed to be independent of soil type potential. Evaporation for the shade trees was estimated using two percent of National Weather Service Class A pan evaporation values and on the basis of canopy sizes of the trees as follows:

$$PE_{i,j,k} = 0.7 \times r^2_{i,j,k} \pi \text{ (ft}^2\text{)} \times \frac{PAN_i}{12} \text{ (ft)} \times 7.48 \left(\frac{\text{gallons}}{\text{ft3}} \right. \qquad [5.7]$$

where $PE_{i,j,k}$ = Potential evapotranspiration on day i, soil j, by a plant of K'th category (gallons).

$r_{i,j,k}$ = Radius of canopy on day i, soil j, plant k (ft) (Since canopy growth was assumed to be independent of soil type, $PE_{i,j,k}$ is actually independent of j)

PAN_i = National Weather Service Class A pan evaporation value on day i (inches).

The consumptive use coefficients ($K_{i,j,k}$) were assumed to be 0.7 irrespective of tree category. However, potential evapotranspiration rates ($PE_{i,j,k}$) for different trees are not the same due to the varying nature of canopy growths ($r_{i,j,k}$).

In this connection, it may be recalled that all relevant soil-moisture balance equations in Chapter 4 were based on "inches of water." These equations were redefined in terms of "gallons of water." With this alternative definition the volume of the soil-moisture reservoir is incorporated into the soil-moisture balance equation. The volume of a soil moisture reservoir for a single tree, as shown

in Figure 5.9, depends on the spread of root structure of the tree and the effective depth of soil horizon. The soil-moisture reservoir for each tree was assumed to be cylindrical in shape with the diameter being equal to canopy size, and the length being equal to the depth of the root structure. The depth of the root structures for trees in all categories was assumed to increase linearly from 36 inches to 84 inches in 20 years. It was further assumed that the moisture is extracted by a tree uniformly from all parts of the soil moisture reservoir.

Irrigation efficiencies for subirrigation and sprinkler irrigation methods were assumed to be 1 and 7, respectively, irrespective of soil type. Percolation and runoff losses were assumed to be zero. Maximum and minimum permitted levels of irrigation for all trees on any soil were assumed to be 1.0 and 0.6 of field capacity, respectively (87).

Vegetation Strategy

The location of areas suitable for trees at White River Lake is shown in Figure 5.10. Campground Number 1, which is the most used campground at present, contains approximately 11 acres of Miles Sandy Loam, and is very suitable for growing shade trees or turf grasses. A five acre plot of Berda Loam on the eastern bank and a 55.3 acre plot of Miles Sandy Loam on the southwest bank of the lake are two other proposed irrigation development sites. There is a 50.2 acre plot of Latom Polar Complex soil located on the west bank. Only the "Polar" part of this plot is suitable for irrigation

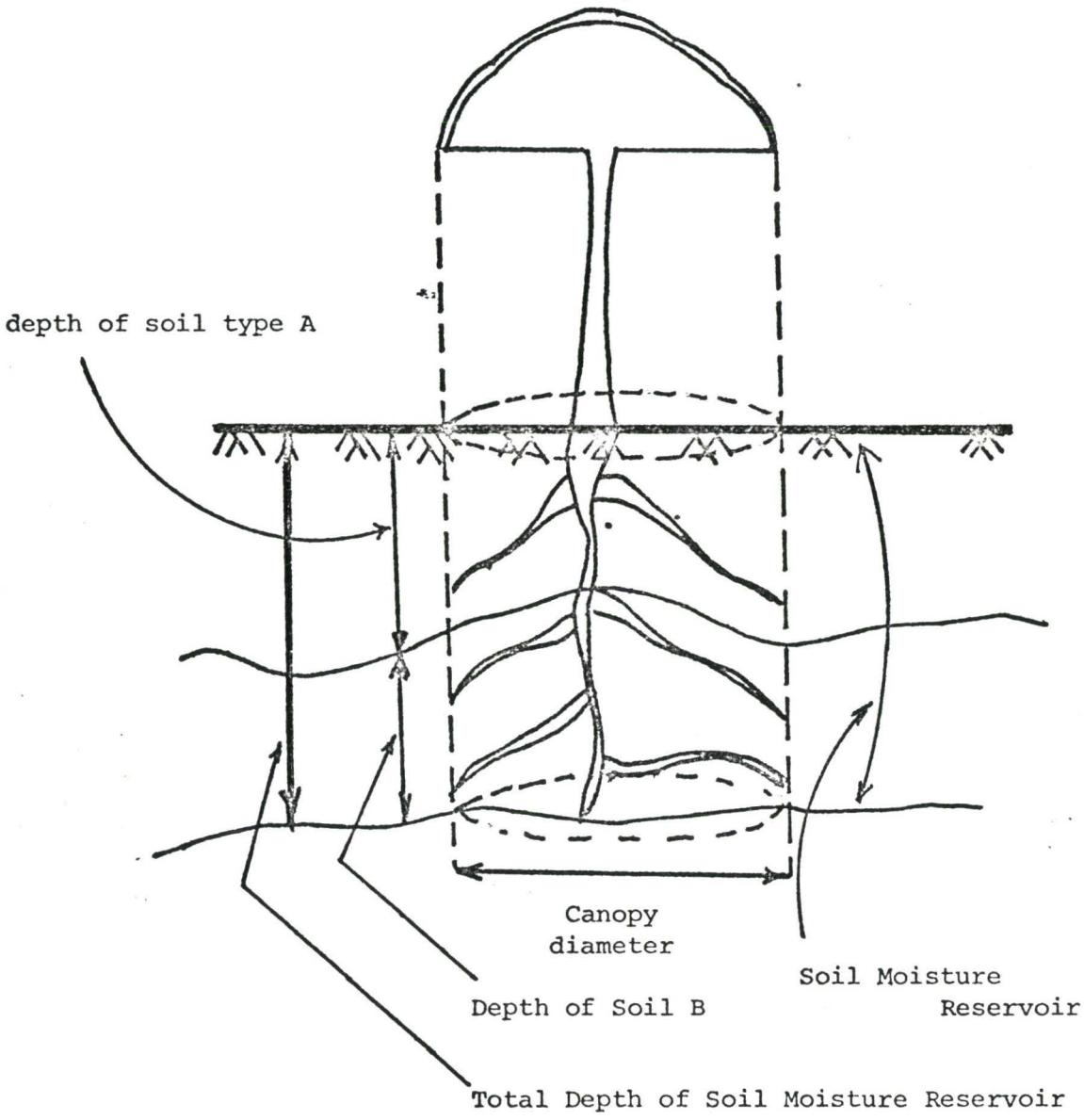

Figure 5.9. Soil moisture reservoir under a tree.

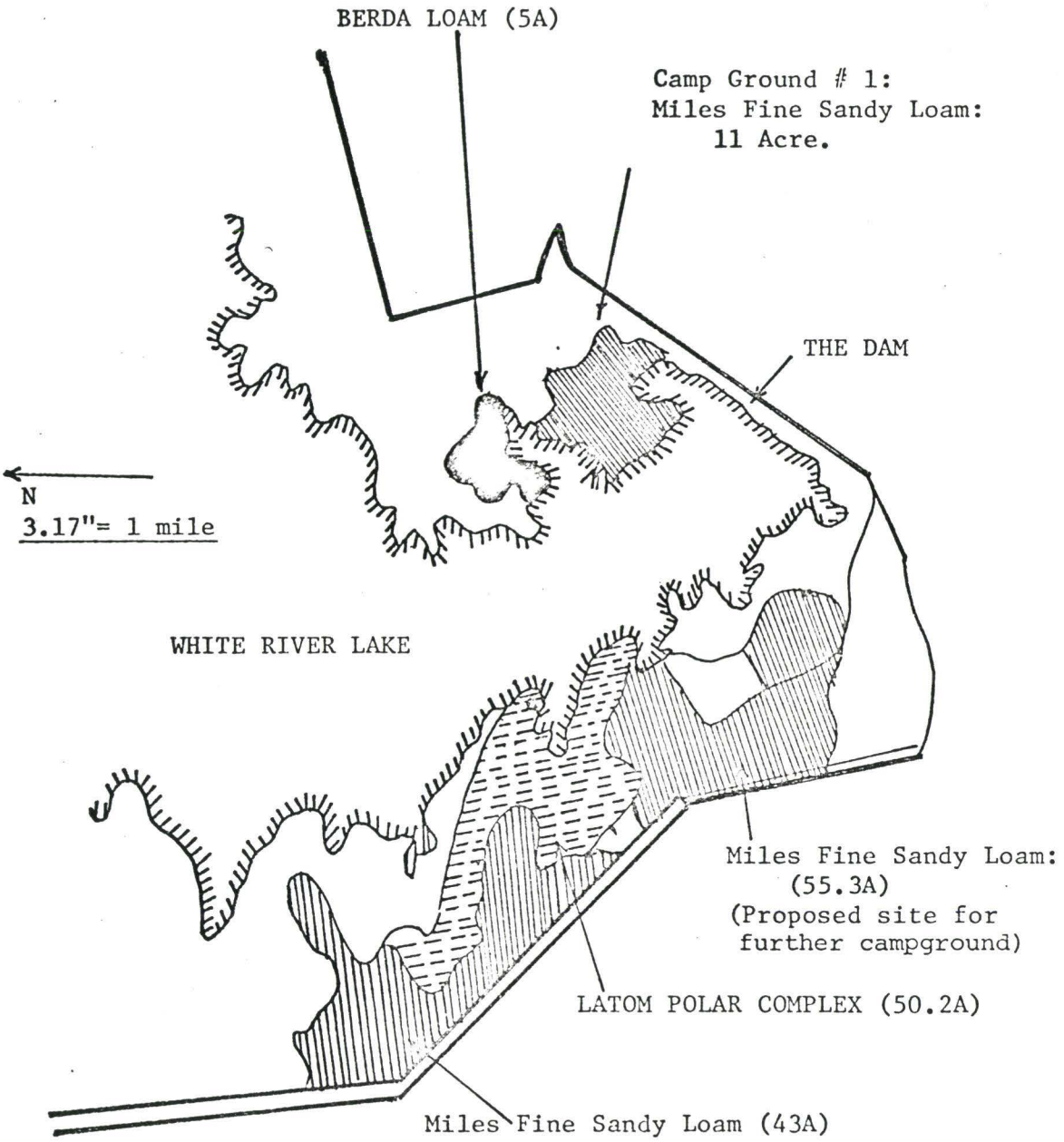

Figure 5.10. Proposed sites for vegetation at White River Lake.

development (3). Another 43 acres of Miles Sandy Loam are located on the west bank. These are the sites which have been considered for irrigation development in this study. Table 5.8 shows six various vegetation strategies evaluated in the simulation model. In selecting the vegetation strategies, emphasis was given on locating the larger shade trees and grassed area in Campground Number 1.

Storage Capacity

Alternative effluent storage capacity levels considered in the simulation model were 80,000 gallons, 200,000 gallons, and 400,000 gallons. The cost of construction for storage tanks assumed in this study are shown in Appendix

Rainfall and Pan Evaporation

The weather station nearest to the case study area is located at Spur, Texas. The station is about eight miles away from White River Lake. Records of daily rainfall and pan evaporation from 1938 to 1972, as collected by U.S. Weather Bureau Station (97) and Texas Agricultural Experimental Station (85) at Spur, Texas, were analyzed to construct the daily rainfall and pan evaporation submodels in this study. Each year was first divided into twelve monthly periods. Daily rainfall and pan evaporation values in each of these periods were determined to be not correlated with each other.[a] Daily rainfall in any period was asssumed nonrandom as indicated by the Wald-Wolfowitz

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[a]Modified Spearman's Rho Test was applied,

TABLE 5.8

ALTERNATIVE VEGETATION STRATEGIES USED IN THE SIMULATION MODEL

Vegetation Strategy Number	Soil Types.[a]	Number of Trees to be Grown			Acres of Grass Land to be Irrigated.
		Trees Type A	Trees Type B	Tree Type C	
Vegetation Strategy #1	Miles Fine Sandy Loam	1050	0	0	10 Acres in Camp Ground 1
	Berda Loam	150	0	0	0
	L.P. Complex	1000	500	20	0
	Total	2200	500	20	10 Acres
Vegetation Strategy #2	Miles Fine Sandy Loam	1050	0	0	10 Acres in Camp Groundl
	Berda Loam	150	0	0	0
	L.P. Complex	0	500	20	0
	Total	1200	500	20	10 Acres in Camp Ground 1
Vegetation Strategy #3	Miles Fine Sandy Loam	1050	0	0	0
	Berda Loam	150	0	0	0
	L.P. Complex	1000	500	20	0
	Total	2200	500	20	0
Vegetation Strategy #4	Miles Fine Sandy Loam	1050	0	0	0
	Berda Loam	150	0	0	0
	L.P. Complex	0	500	20	0
	Total	1200	500	20	0
Vegetation Strategy #5	Miles Fine Sandy Loam	2050	0	0	0
	Berda Loam	150	0	0	0
	L.P. Complex	0	500	20	0
	Total	2200	500	20	0
Vegetation Strategy #6	Miles Fine Sandy Loam	2050	500	20	0
	Berda Loam	150	0	0	0
	L.P. Complex	0	0	0	0
	Total	2200	500	20	0

[a]Reference Table: 5.5.

[b]Reference Table: 5.6.

run test. However, daily pan evaporation for each of these monthly periods was determined to be random from the Wallis-Moore phase test.

Past records of annual rainfall from 1942 to 1972 were used to categorize the years into three types: i) years with heavy annual rainfall (more than 25.30 inches); ii) years with medium annual rainfall (more than 16.80 inches but less or equal to 25.30 inches); and iii) years with low annual rainfall (less than 16.80 inches). The probabilities of experiencing years with heavy, medium or low annual rainfall have been found to be .3705, .3342, and .2942, respectively.

For each of these three categories of annual rainfall, the following probabilities were calculated from past data:

$$P_0 = P\,[R_i = 0/R_{i-1} = 0]$$

$$P_1 = P\,[R_i = 0/R_{i-1} > 0]$$

$$P_2 = P\,[R_i = 0/R_{i-1} > 0,\ R_{i-2} > 0]$$

$$P_n = P\,[R_i = 0/R_{i-1} > 0,\ R_{i-2} > 0,\ \ldots,\ R_{i-n} > 0]$$

where R_i = Amount of rain on day i, and n is the minimum number of rainy days found to be "bunched" together in past records. Table 5.9 shows these conditional probabilities. The computer simulation model uses these probabilities to generate the rain days.

The discrete empirical probability distribution for the amount of daily rainfall as calculated from past records are shown in Table 5.10, 5.11 and 5.12. Once the simulation model generates a rainy day, it uses these probabilities to generate the amount of rainfall on that day.

TABLE 5.9

CONDITIONAL PROBABILITIES OF ZERO AMOUNT OF DAILY RAINFALL FOLLOWING A RAINY DAY OR A SEQUENCE OF RAINY DAYS AT WHITE RIVER LAKE, TEXAS[a]

Months	Heavy Annual Rainfall (Annual Rainfall is above 25.31")						Medium Annual Rainfall (Annual Rainfall is from 16.80" to 25.30")					Low Annual Rainfall (Annual Rainfall is below 16.80")			
	P_0	P_1	P_2	P_3	P_4	P_5	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3
January	.905	.650	.428	.250	.330	.500	.918	.750	1.000	1.000	1.000	.959	.668	.500	1.000
February	.875	.565	.500	.600	1.000	1.000	.724	.644	.400	.333	.500	.900	.583	.400	1.000
March	.880	.685	.600	1.000	1.000	1.000	.880	.445	.600	1.000	1.000	.885	.333	1.000	1.000
April	.816	.600	.500	.400	.660	1.000	.800	.750	.875	1.000	1.000	.859	.833	.667	1.000
May	.796	.648	.500	.750	.660	1.000	.816	.530	.625	.333	.500	.840	.688	.400	1.000
June	.826	.679	.242	.570	.530	1.000	.785	.800	.500	.500	1.000	.812	.636	.625	1.000
July	.886	.556	.625	.660	1.000	1.000	.850	.533	.853	1.000	1.000	.878	.687	.600	.700
August	.823	.596	.583	.600	.500	1.000	.730	.357	.500	.333	.500	.873	.750	.667	1.000
September	.857	.665	.256	.500	.660	1.000	.843	.400	.778	1.000	1.000	.863	.778	.750	1.000
October	.860	.445	.416	.143	.834	1.000	.875	.539	.834	1.000	1.000	.900	.445	.800	1.000
November	.862	.666	.500	.750	1.000	1.000	.905	.700	.660	1.000	1.000	.940	.625	.666	.934
December	.885	.667	.250	.560	1.000	1.000	.895	.635	.750	1.000	1.000	.893	.571	.333	1.000

[a] $P_0 = P\left[R_i = 0 / R_{i-1} = 0\right]$; $P_n = P\left[R_i = 0 / R_{i-1} > 0, R_{i-2} > 0, \ldots R_{i-n} > 0\right]$, Where R_n is the amount of rainfall in day i.

TABLE 5.10

PROBABILITIES OF DAILY AMOUNT OF RAINFALL IN VARIOUS MONTHS IN A YEAR WITH HEAVY ANNUAL RAINFALL, WHITE RIVER LAKE, TEXAS[a]

Months	Probabilities									
	.010" to .100"	.101" to .200"	.201" to .300"	.301" to .400"	.401" to .500"	.501" to .600"	.601" to .800"	.801" to 1.200"	1.200" to 1.800"	1.800" to 2.600"
January	.702	.108	.055	.027	.027	.041	.040	.000	.000	.000
February	.600	.200	.175	.025	.000	.000	.011	.000	.000	.000
March	.592	.186	.118	.018	.037	.038	.011	.000	.000	.000
April	.456	.181	.108	.115	.021	.079	.018	.017	.005	.000
May	.333	.197	.183	.143	.032	.016	.040	.0178	.019	.019
June	.347	.180	.063	.040	.062	.123	.040	.123	.012	.010
July	.300	.100	.133	.100	.034	.034	.100	.035	.092	.070
August	.347	.133	.120	.054	.036	.037	.040	.122	.071	.040
September	.333	.166	.024	.023	.048	.095	.048	.042	.050	.000
October	.471	.145	.125	.143	.059	.057	.000	.000	.000	.000
November	.514	.216	.036	.080	.077	.077	.000	.000	.000	.000
December	.658	.158	.068	.046	.074	.000	.000	.000	.000	.000

[a]Annual rainfall is more than 25.30"

TABLE 5.11

PROBABILITIES OF DAILY AMOUNT OF RAINFALL IN VARIOUS MONTHS IN A YEAR WITH MEDIUM AMOUNT OF ANNUAL RAINFALL, WHITE RIVER LAKE, TEXAS[a]

Months	Probabilities									
	.010" to .100"	.101" to .200"	.201" to .300"	.301" to .400"	.401" to .500"	.501" to .600"	.601" to .800"	.801" to 1.200"	1.20" to 1.800"	1.80" to 2.600"
January	.714	.286	.000	.000	.000	.000	.000	.000	.000	.000
February	.520	.360	.080	.040	.000	.000	.000	.000	.000	.000
March	.375	.625	.000	.000	.000	.000	.000	.000	.000	.000
April	.525	.094	.191	.095	.095	.000	.000	.000	.000	.000
May	.332	.228	.094	.066	.032	.064	.129	.032	.023	.000
June	.259	.186	.110	.016	.019	.075	.073	.075	.150	.040
July	.304	.218	.086	.042	.175	.045	.042	.048	.040	.000
August	.296	.097	.203	.108	.082	.061	.108	.045	.000	.000
September	.292	.154	.056	.174	.039	.059	.056	.077	.093	.000
October	.4000	.150	.100	.100	.060	.050	.050	.090	.000	.000
November	.389	.214	.215	.065	.030	.029	.029	.029	.000	.000
December	.562	.313	.125	.000	.000	.000	.000	.000	.000	.000

[a]Annual rainfall is within 16.80" to 25.30"

TABLE 5.12

PROBABILITIES OF DAILY AMOUNT OF RAINFALL IN VARIOUS MONTHS IN A YEAR WITH LOW ANNUAL RAINFALL, WHITE RIVER LAKE, TEXAS[a]

Months	Probabilities								
	.010" to .100"	.101" to .200"	.201" to .300"	.301" to .400"	.401" to .500"	.501" to .600"	.601" to .800"	.801" to 1.200"	1.200" to 1.800"
January	.667	.333	.000	.000	.000	.000	.000	.000	.000
February	.550	.100	.250	.125	.125	.000	.000	.000	.000
March	.450	.200	.050	.050	.050	.150	.050	.050	.000
April	.409	.182	.099	.182	.099	.029	.000	.000	.000
May	.500	.063	.062	.042	.041	.040	.083	.084	.084
June	.363	.212	.151	.034	.030	.030	.030	.075	.075
July	.541	.125	.063	.065	.027	.025	.043	.081	.000
August	.652	.173	.029	.028	.028	.028	.043	.019	.000
September	.411	.210	.200	.024	.019	.019	.058	.059	.000
October	.533	.222	.115	.020	.055	.055	.100	.000	.000
November	.785	.108	.107	.000	.000	.000	.000	.000	.000
December	.667	.208	.125	.000	.000	.000	.000	.000	.000

[a]Annual rainfall is less than 16.80"

Egon Pearson's test and Geary's test for Kurtosis provided the evidence of positive skewness of daily pan evaporation for all monthly periods. Gamma distribution functions were fitted to daily pan evaporation data for various periods and were verified by using Kolmogorov-Smirnov "goodness of fit" test. The values of σ and β in these distributions are shown in Table 5.13. Phillip's (61) FORTRAN IV program was used to generate gamma variates from these parameters. The values of daily pan evaporation thus generated were converted to standard Weather Bureau Class A pan evaporation measurements (4). This conversion was necessary because the raw pan evaporation data were from two feet diameter Y pans.

CHAPTER 6

RESULTS AND ANALYSIS

The purpose of this chapter is to present and analyze the results of the model as applied to White River Lake, Texas. Important aspects of various components of the system and their effects on other components are presented individually before discussing the behavior of the entire system as a whole.

Volume of Sewage Generated

Figure 61. and Table 6.1 show the simulated total volume of sewage generated at White River Lake at various levels of developments from 1975 to 1994. The volume of sewage generated at the site during the entire planning period (1975-1994) is independent of central treatment plant and irrigation alternatives. However, due to infiltration, the amount of sewage collected by the gravity system is more than that collected by a pressure sewer system. The difference between the volume of sewage collected by these systems gradually increases as the number of vacation homes in the planning period is increased. This is due to the fact that additional sewer pipes are installed for additional vacation homes, and hence it increases the amount of infiltration in the gravity sewers. Rain water or underground water infiltrated into a gravity sewer system reduces the BOD concentration of the collected wastewater. But, it does not reduce

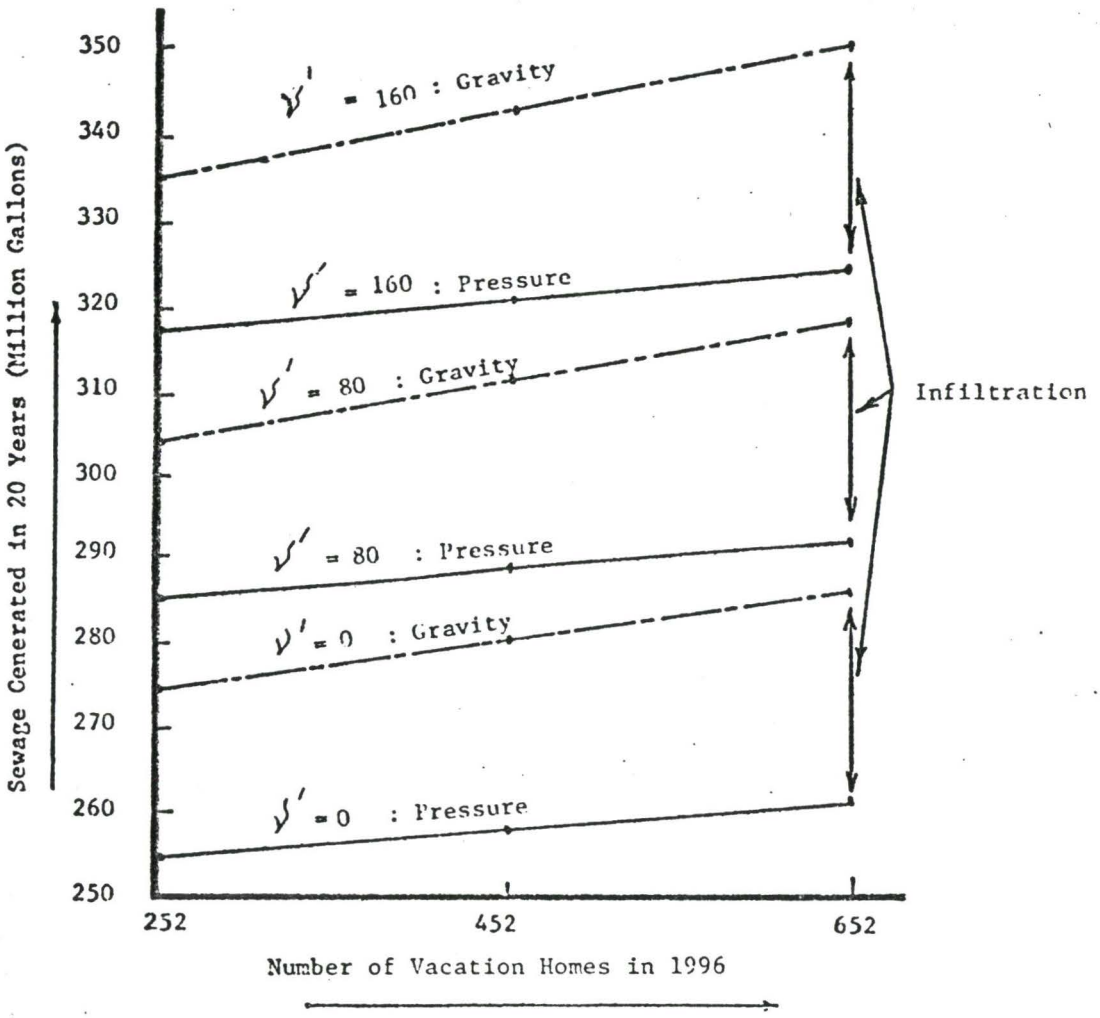

Figure 6.1. Volume of sewage collected at White River Lake, Texas from 1965-1994 at various levels of development by alternative collection systems.

TABLE 6.1

SIMULATED TOTAL VOLUME OF SEWAGE COLLECTED BY ALTERNATIVE COLLECTION METHODS AT WHITE RIVER LAKE, TEXAS FROM 1976 TO 1994 AT VARIOUS ASSUMED RATES OF DEVELOPMENT

μ' %	Number of Vacation Homes in 1994	Million Gallons of Sewage Collected in 20 Years (1965-1994)		Infiltration in Gravity Sewers in Million Gallons
		Pressure Collection	Gravity Collection	
0.0	252	254.79	274.55	19.76
	452	257.95	280.75	22.80
	652	261.54	286.23	24.69
80.	252	285.23	305.44	20.21
	452	289.21	311.95	22.74
	652	292.79	318.46	25.26
160.	252	317.11	336.87	19.76
	452	320.27	343.32	23.05
	652	323.40	350.12	26.72

the design BOD load of the treatment plant because the influent sewage is not diluted in a day with zero amount of daily rainfall. On the contrary, as will be seen in later sections of this chapter, a gravity collection sewer system increases the treatment costs due to increased sewage volume.

Since the volume of sewage collected in a gravity sewer is more than that collected by a pressure sewer system, more effluent is available for irrigation. Hence, for a particular irrigation method, the amount of water to be pumped from the adjacent lake to meet the irrigation demand is less in the case of a gravity collection system. Figure 6.2 and Table 6.2 show the amount of water to be pumped from the lake to meet the irrigation demand for Vegetation Strategy 1 at alternative collection and irrigation methods for various assumed rate of developments. Figures 6.2 and 6.3 show the effects of increasing the capacity of the effluent storage, and the interaction of collection's methods and irrigation alternatives on the amount of water from the lake to supplement the irrigation requirement of vegetation strategy 1. If the capacity of the effluent storage is increased, the amount of water to be pumped from the lake gradually decreases. However, as can be seen from Figure 6.3 this reduction of lake water needed is not directly proportional to the capacity of storage. This is obvious because conceptually there should be an ultimate maximum size of the storage which would provide maximum possible utilization of the treated effluent for the corresponding vegetation strategy. Figure 6.3 shows that for pressure collection and submatic irrigation,

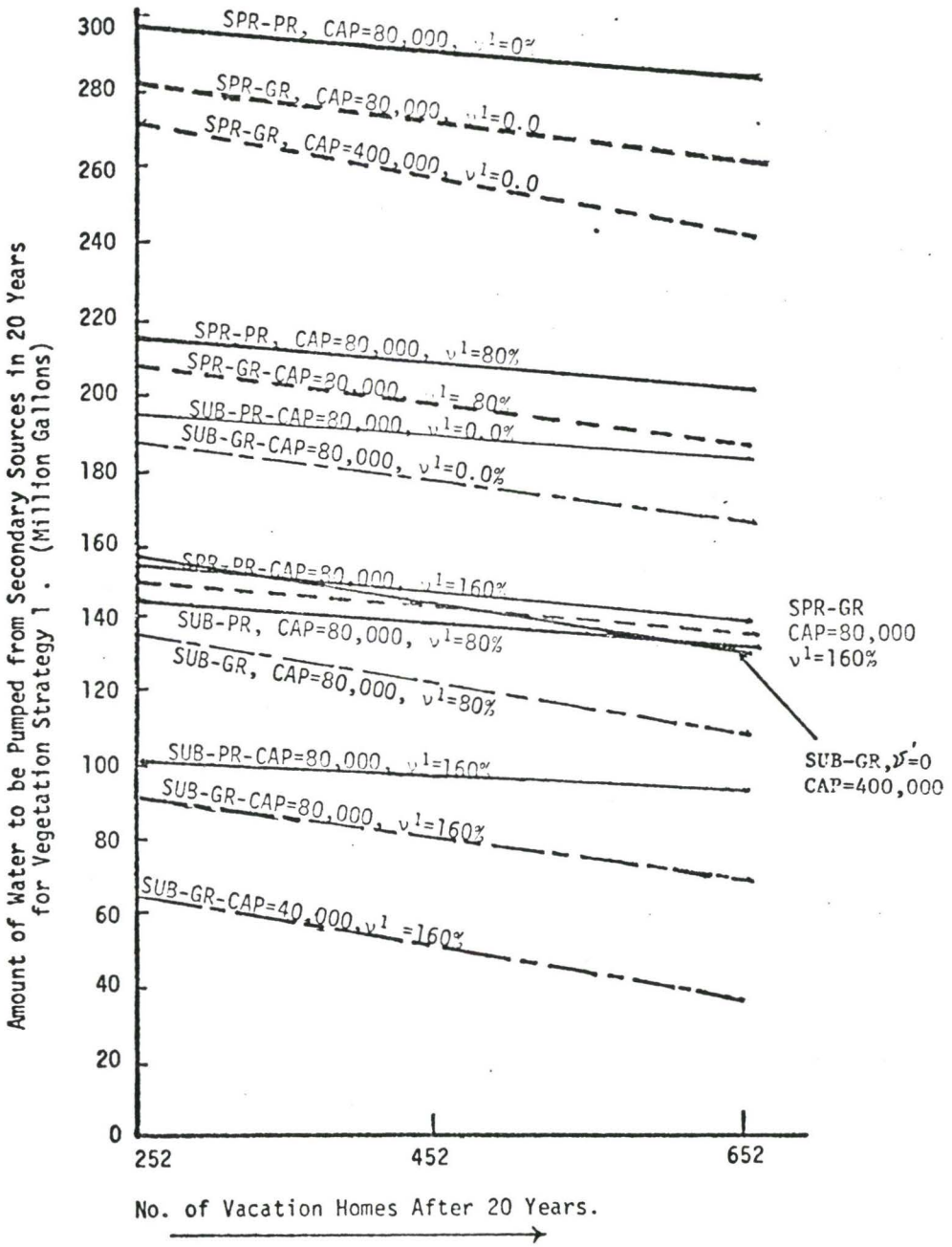

Figure 6.2. Amount of water to be pumped in 20 years from secondary sources for irrigation at various sewage collection and irrigation alternatives for vegetation strategy.

TABLE 6.2

. AMOUNT OF WATER TO BE PUMPED FROM THE LAKE AND AMOUNT OF EFFLUENT TO DISPOSE OF AT ALTERNATIVE COLLECTION AND IRRIGATION METHODS FOR VEGETATION STRATEGY 1 IN 20 YEARS AT VARIOUS EFFLUENT STORAGE CAPACITY

Capacity of Storage (Gallons)	v'	Number of Vacation Homes after 20 years	Amount of Water to Be Pumped From the Lake (million gallons)				Amount of Effluent to Dispose of (Million Gallons)			
			Gravity Collection		Pressure Collection		Gravity Collection		Pressure Collection	
			Sprinkler Irrig.	Submatic Irrig.	Sprinkler Irrig.	Submatic Irrig.	Sprinkler Irrig.	Submatic Irrig.	Sprinkler Irrig.	Submatic Irrig.
80,000	0.0	252	278	186.2	297.0	194.4	5.6	13.7	4.5	8.4
		452	272.2	175.0	291.6	188.9	6.1	13.9	5.2	8.5
		652	a	a	286.7	183.0	a	14.8	5.9	8.6
	80.0	252	206	136.1	a	a	7.5	16.1	a	a
		452	199.3	125.0	214.3	137.3	8.6	17.7	7.7	11.1
		652	193.8	112.4	208.5	131.3	9.3	17.9	7.9	11.4
	160.	252	153.7	88.6	159.2	101.6	10.1	19.3	11.0	14.6
		452	146.1	82.4	152.0	96.9	11.0	19.5	11.7	14.9
		652	140.5	75.8	146.4	92.2	11.5	19.7	11.9	15.3
200,000	0	252	a	a	a	194.2	a	a	a	6.8
		452	a	a	a	187.4	a	a	a	7.0
		652	a	a	a	182.8	a	a	a	7.1
	80	252	201.2	117.7	a	a	6.7	13.4	a	a
		452	193.8	110.2	a	a	6.9	13.6	a	a
		652	188.7	103.2	a	a	7.7	13.9	a	a
	160	252	a	71.5	a	101.6	a	15.6	a	11.5
		452	a	64.9	a	96.9	a	16.0	a	11.6
		652	a	57.8	a	92.2	a	16.2	a	12.2
400,000	0	252	270.8	158.	296.6	194.1	2.6	8.0	1.76	4.7
		452	253.7	146.5	290.2	187.0	3.3	8.3	1.87	4.8
		652	a	134.2	a	182.7	a	8.5	a	4.9
	80	252	198.4	108.4	158.2	a	4.7	10.4	2.7	a
		452	192.0	98.1	151.7	a	4.8	10.6	2.8	a
		652	184.7	84.1	146.4	a	4.9	10.8	2.9	a
	160	252	a	60.6	158.1	101.6	a	12.5	3.1	9.4
		452	a	52.3	151.3	96.9	a	12.6	3.2	9.6
		652	a	45.5	145.1	92.2	a	12.7	3.3	9.7

[a] Not simulated

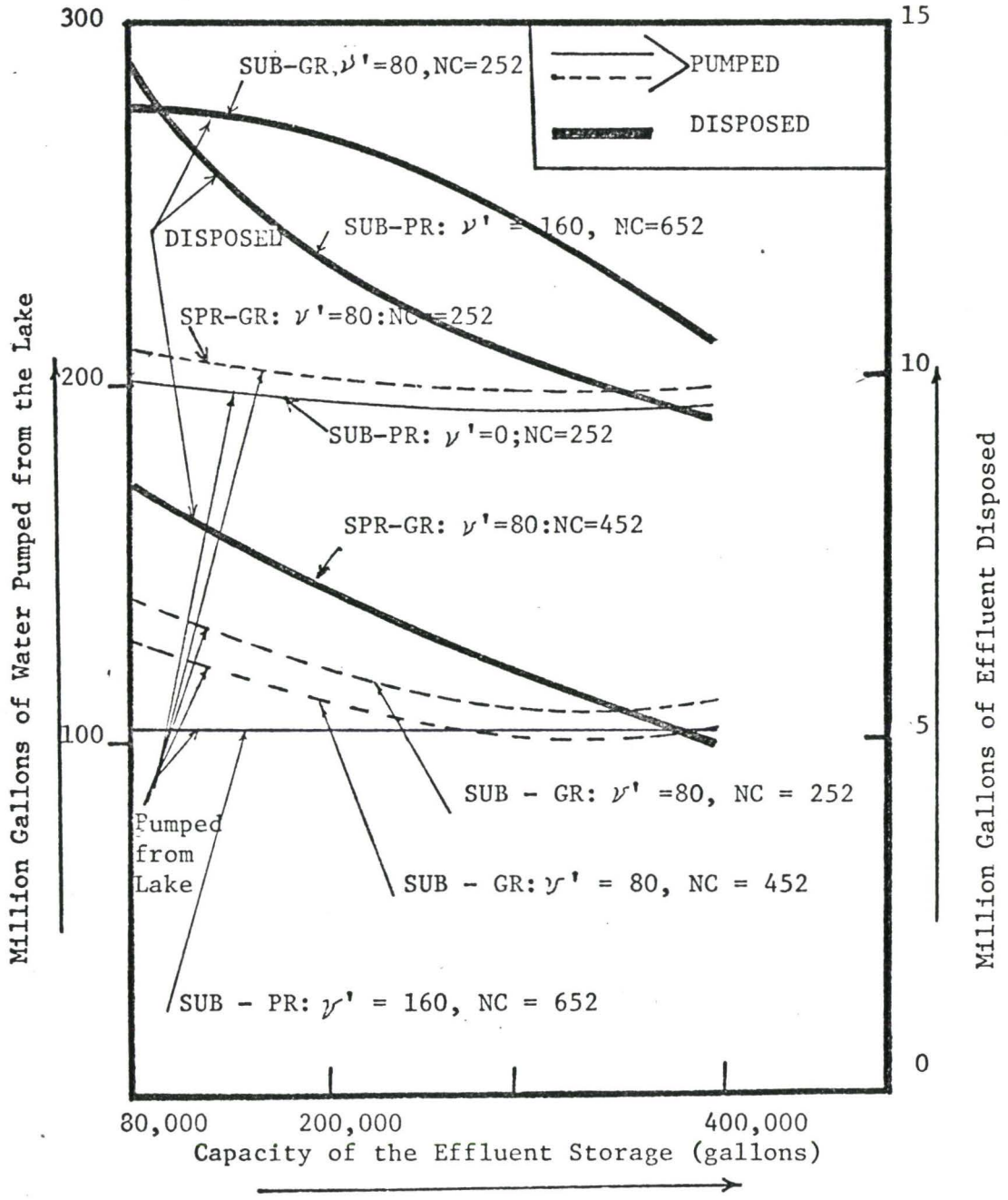

Figure 6.3. Amount of water to be pumped from the lake and amount of effluent to dispose off in 20 years (from 1965 to 1994) at White River Lake, Texas at alternative sewage collection and irrigation method for vegetation strategy 1 corresponding to various capacity of the effluent storage.

the capacity of the effluent storage does not have any effect on the amount of supplementary water if the development of the site is assumed to be defined by ν' = 160% and $(NC)_{1994}$ = 652. Figure 6.2 shows that for any specific combination of ν', $(NC)_{1994}$ and storage capacity, submatic irrigation of vegetation strategy 1 together with a gravity collection system needs the least amount of lake water.

Figures 6.2 and 6.3 show that for most of the combinations of collection and irrigation alternatives, the storage capacity has a notable effect on the amount of supplementary water needed to meet the irrigation demand. However, if the value of lake water is to be ten cents per 1000 gallons, as assumed in this study, the savings in cost by increasing the capacity of the storage is not justified from the points of view of the total system cost. This is due to the fact that the cost of increasing storage capacity is greater than the corresponding cost of lake water saved. For example, Figure 6.2 shows that if $(NC)_{1994}$ is 252 and ν' is 0.0 percent, then about 28.2 million gallons of lake water to be pumped is reduced by increasing the capacity of the storage from 80,000 gallons to 400,000 gallons for the combination of submatic irrigation-gravity collection and vegetation strategy 1. The present worth of cost of lake water along with pumping costs for these decisions are shown in Figure 6.4 by the lines "0(P), ν' = 0,GR-SUB" and "0(P), ν' = 0, GR-SUB: CAPACITY = 400,000" at $(NC)_{1994}$ = 252. These lines show that about 2900 dollars are saved by reducing lakewater requirements as a result of increasing the capacity of the effluent storage from 80,000 to 400,000 gallons.

But, cost for the storage facility is increased by $14,780 if capacity is increased from 80,000 gallons to 400,000 gallons. Since vegetation strategy 1 involves the maximum number of trees and acres of grassed land among all the simulated vegetation strategies, the irrigation requirement for vegetation strategy 1 is maximum. In the case of other vegetation strategies simulated in this study, the reduction in lakewater requirements and corresponding costs associated with increasing the capacity of storage are even less. The amount of effluent to be disposed off for alternative collection and irrigation methods with different design capacities of the effluent storage facility are tabulated in Table 6.2. These have been plotted for a few selected combinations of collection and irrigation alternatives in Figure 6.3. In Figure 6.3, "Gravity and Pressure Collection," "Stabilization Pond," and "Submatic and Sprinkler Irrigation" are abbreviated as "GR," "PR," "STAB," "SUB," and "SPR," respectively.

Collection Methods and Their Sensitivity Towards Further Development

Various simulated cost figures for the collection alternatives at various assumed values of ν' and $(NC)_{1994}$ are tabulated in Table 6.3. The costs of the collection systems are more sensitive to the number of vacation homes than are treatment plant costs. If ν' is less than 160 percent, the installation cost for a gravity collection system is higher than the installation cost of a pressure collection system. However, as the number of vacation homes increases, the difference between the installation costs for gravity and pressure

TABLE 6.3

INSTALLATION COSTS, PRESENT WORTHS OF OPERATION AND MAINTENANCE COSTS AND TOTAL COSTS FOR ALTERNATIVE COLLECTION METHODS AT VARIOUS ASSUMED RATES OF DEVELOPMENTS AT WHITE RIVER LAKE, TEXAS

ν' / %	Number of vacation homes in 1994	Costs in dollars					
		Gravity Collection			Pressure Collection		
		Fixed Cost	Present Worths of Operation & Maintenance Costs	Total Cost	Fixed Cost	Present Worths of Operation & Maintenance Costs	Total Cost
0.0	252	272915	22610	295525	214382	23683	238065
	452	330215	25103	355318	289662	23936	313598
	652	387585	28051	416356	364941	24203	389144
80.	252	272915	24360	297275	228507	25820	254327
	452	330215	26903	357118	303789	36118	339907
	652	387585	29547	417132	379070	36474	415544
160.	252	272915	29627	302542	242636	49786	292422
	452	330215	29975	360190	317917	50116	368033
	652	387585	30410	417995	393198	50621	443819

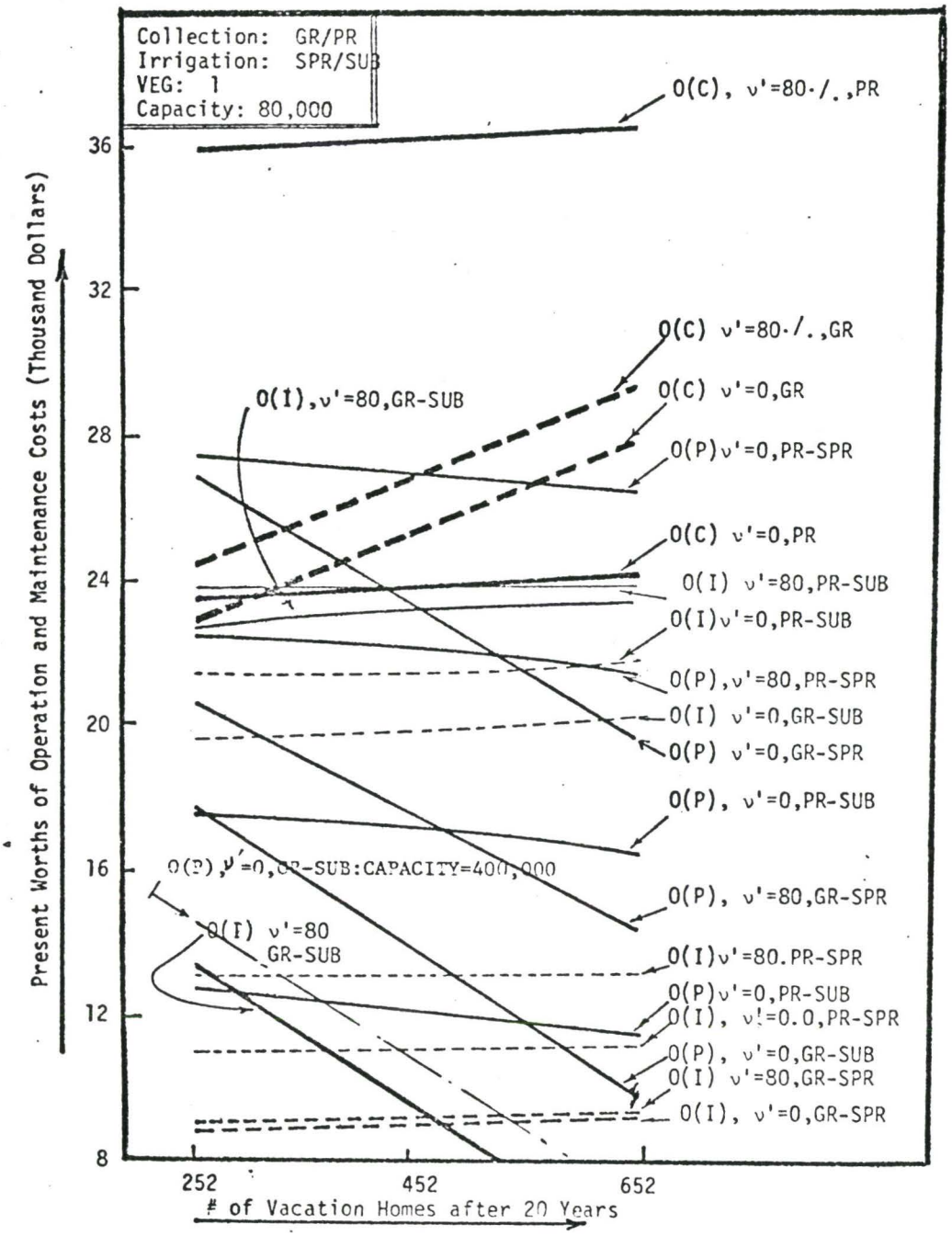

Figure 6.4. Present worths of various major costs components of the alternative sewage collection, and irrigation system for vegetation strategy 1, and storage capacity = 80,000 gallons.

collection decreases, and for 582 vacation homes, the installation cost for gravity collection methods becomes less than that for pressure collection if ν' is 160 percent. This is illustrated in Figure 6.5 and Table 6.3. In Figure 6.5, F(C) and T(C) designate fixed cost and total cost for the collection systems.

Figure 6.5 shows that at any ν', the operation and maintenance costs of a pressure collection method are higher than for a gravity collection method as long as $(NC)_{1994}$ is more than 300. That is why, when total costs of the collection systems (i.e., fixed costs + operation and maintenance costs) are considered, the gravity collection method becomes cheaper than the pressure collection method at ν' = 160 and $(NC)_{1994}$ = 350. However, pressure collection is always cheaper than gravity collection as long as ν' is less than 160 for any number of vacation homes at the site.

Treatment Costs and its Interaction with Collection Alternatives

Construction costs, present worths of operation and maintenance costs, and total costs for two selected treatment alternatives are shown in Table 6.4 and Figure 6.6. The treatment alternatives illustrated here are a primary treatment plant along with a stabilization pond and a package treatment plant. Both treatment units are entailed with an effluent storage of 80,000 gallons. The purpose of presenting Table 6.4 in this section is only to show the characteristics of treatment costs corresponding to each alternative collection method. All other treatment alternatives and their relationships with

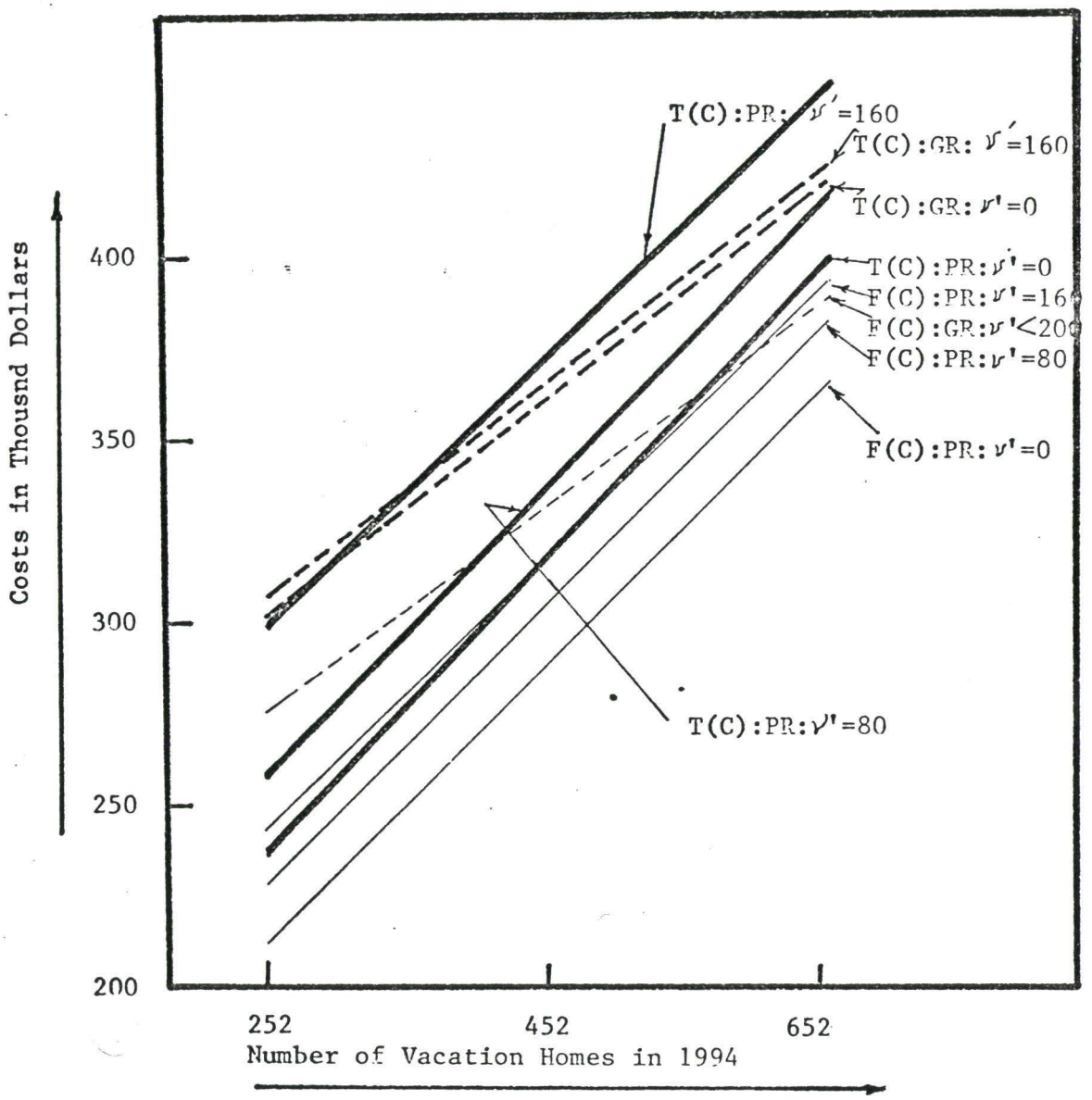

Figure 6.5. Fixed costs for installation and total costs for alternative collection methods at various assumed rates of development in White River Lake, Texas.

TABLE 6.4

CONSTRUCTION COSTS, OPERATION AND MAINTENANCE COSTS AND TOTAL COSTS FOR DIFFERENT TREATMENT PLANTS WITH AN EFFLUENT STORAGE OF 80,000 GALLONS ASSOCIATED WITH ALTERNATIVE COLLECTION METHODS AT VARIOUS ASSUMED RATES DEVELOPMENT AT WHITE RIVER LAKE, TEXAS

Treatment Plants	$\frac{S'}{\%}$	Number of Vacation Homes in 1994	Costs in Dollars					
			Gravity Collection			Pressure Collection		
			Fixed Cost	Present Worths of Operation & Maintenance Costs	Total Cost	Fixed Cost	Present Worths of Operation and Maintenance Cost	Total Cost
Primary Plant and Stabilization Pond	0	252	92698	21608	114306	74325	20666	94991
		452	100373	21830	122203	77385	20702	98087
		652	a	a	a	81395	20855	102250
	80	252	112698	23134	135932	a	a	a
		452	129033	23286	152319	99105	21833	120938
		652	144985	23490	168475	102675	21952	124627
	160	252	117143	24661	141804	108456	23216	131672
		452	129521	24908	154429	111579	23316	134895
		652	145473	25042	170515	117043	23420	140463
Package Treatment Plant	0	252	95072	34257	129329	75974	33451	109430
		452	100353	34430	134783	78910	33495	112405
		652	a	a	a	81782	33566	115348
	80	252	111072	35426	146498	a	a	a
		452	124953	35598	160551	95969	34669	130638
		652	138132	35754	173886	99131	34705	133836
	160	252	126951	37406	164357	110100	35636	145736
		452	147912	37725	185637	112482	35687	148169
		652	161057	37997	199054	114834	35714	150548

[a]Not simulated

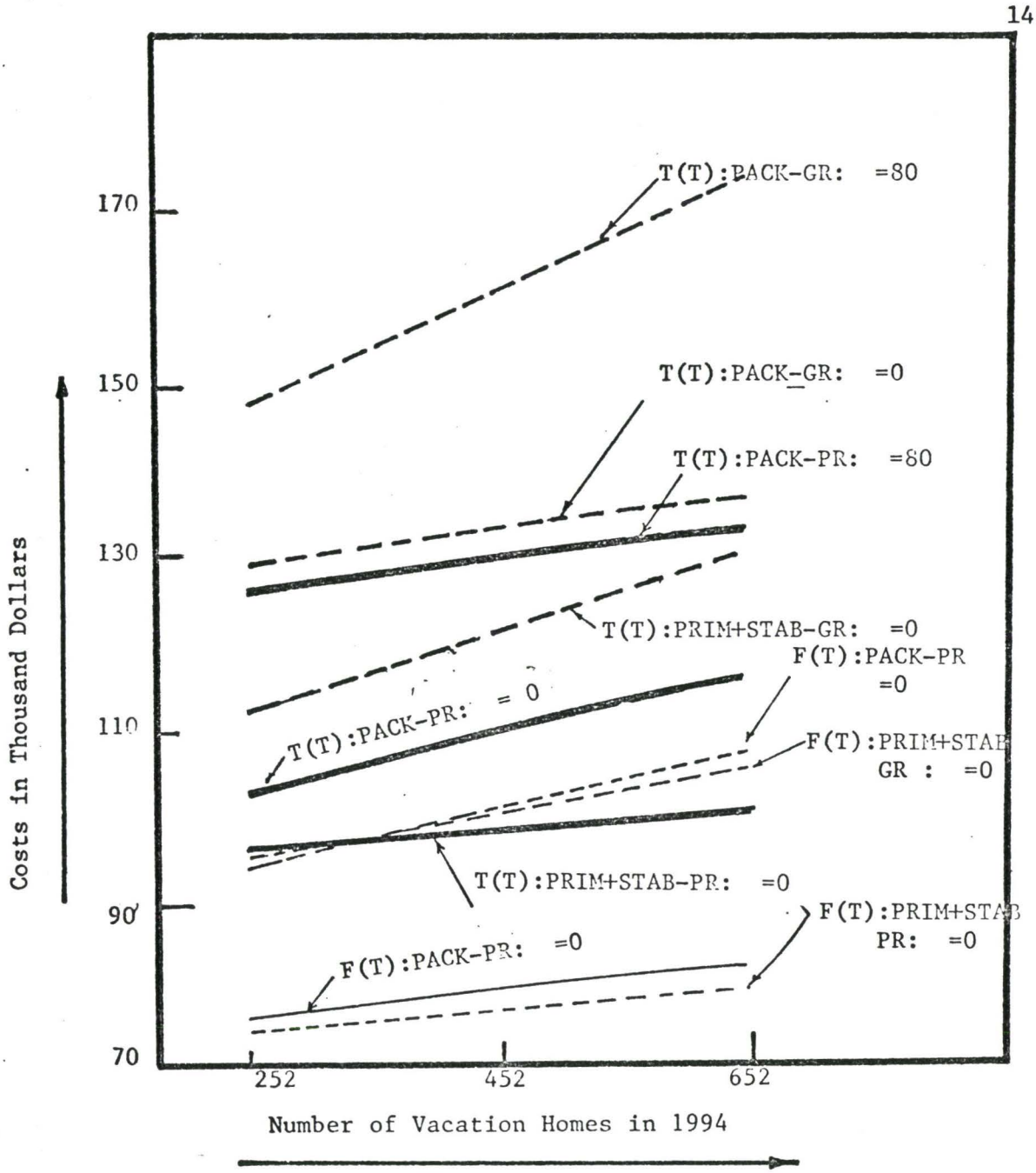

Figure 6.6. Costs of various treatment plants with an effluent storage of 80,000 gallons connected to alternative collection methods at different assumed rates of developments at White River Lake, Texas.

collection and irrigation alternatives for various vegetation strategies are discussed in a later section of this chapter.

Since the volume of sewage collected by a gravity system is more than that collected by a pressure collection system, the construction and operation costs are notably higher in the case of gravity collection. Figure 6.6 illustrates this characteristic. In Figure 6.6, T(T) and F(T) stand for total cost and total fixed cost of the treatment plants, respectively.

Irrigation Costs and its Interactions

Irrigation costs are highly dependent upon the collection method, type of treatment plant, and vegetation strategy. It is not possible to isolate the irrigation costs from combinations of other system components to illustrate the nature of irrigation costs without discussing the associated collection-treatment and vegetation alternatives. A discussion of irrigation cost characteristics is provided in the next section along with the total costs for the entire collection-treatment and irrigation system.

Simulated Costs for Collection-Treatment and Irrigation System

The purpose of this section is to present and analyze system costs for various collection-treatment and irrigation alternatives. The first part of the section discusses the system costs and different components for all collection-treatment and irrigation alternatives corresponding to vegetation strategy 1. In a later part of

this section, only the least cost combination of treatment-collection and irrigation alternatives corresponding to various vegetation strategies is presented.

Tables 6.5, 6.6, 6.7, 6.8 and 6.9 show the various components of fixed costs, present worth of operations and maintenance costs, total fixed costs and total system costs for different combinations of collection and treatment plants incorporated with a sprinkler irrigation system for vegetation strategy 1. Tables 6.10, 6.11, 6.12 and 6.13 show similar cost items for subirrigation. Cost components from the tables are plotted against $(NC)_{1994}$ for different values of ν' and an effluent storage of 80,000 gallons in Figures 6.7, 6.8, 6.9, 6.10, 6.11, 6.12, 6.13, 6.14, and 6.15. In all of these figures and tables, T(S), T(F), F(T), F(C) and F(I) represent total system costs, total fixed cost, fixed cost for treatment plant, fixed cost for collection systems and fixed cost for irrigation, respectively. Fixed costs for an irrigation system shown in these tables and figures include planting costs of the trees associated with vegetation strategy 1, and installation costs of the irrigation system.

These tables show that in the case of vegetation strategy 1, if the storage capacity is increased from 80,000 gallons to 400,000 gallons, total operation and maintenance cost of the entire system is reduced by 500 to 600 dollars irrespective of the kind of treatment plant. However, the fixed cost of the system due to increasing the capacity of the storage increases at a higher rate than the corresponding savings in costs, and hence, total system costs increases with the increased capacity of the effluent storage.

TABLE 6.5

TOTAL SYSTEM COSTS AND ITS COMPONENTS FOR A PRIMARY TREATMENT PLANT AND STABILIZATION POND ASSOCIATED WITH ALTERNATIVE COLLECTION METHODS AND SPRINKLER IRRIGATION FOR VEGETATION STRATEGY 1 AT VARIOUS ASSUMED RATES OF DEVELOPMENTS AT WHITE RIVER LAKE, TEXAS

Capacity of Effluent Storage (Gallons)		Number of Vacation Homes in 1994	F(I): Fixed Cost for Irrigation System (dollars)	F(C): Fixed Cost for Collection System (Dollars)		F(T): Fixed Cost for Treatment (Dollars)		T(F): Total Fixed Cost (Dollars)		T(O): Total Operation and Maintenance Cost (Dollars)		T(S): Total System Cost (Dollars)	
				Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure
80000	0	252	185110	272915	214382	92698	74325	550723	473817	116745	118550	667459	592367
		452		330215	289662	100373	77385	615698	552157	116606	118505	732304	670662
		652		a	364941	a	81395	a	631446	a	118500	a	749946
	80	252	185110	272915	a	112698	a	570723	a	116680	a	687403	a
		452		330215	303789	129033	99105	644363	588004	116570	130009	759128	718013
		652		387585	379070	144985	102675	717680	666855	116441	130096	834121	796951
	160	252	185110	272915	242636	117143	108450	575168	539325	116751	139429	691919	678754
		452		330215	317917	129521	111579	644846	611477	116502	139530	761348	751007
		652		387585	393198	145473	117043	718168	695351	116821	139895	834989	835246
200000	0	252	185110	a	a	a	a	a	a	a	a	a	a
		452		a	a	a	a	a	a	a	a	a	a
		652		a	a	a	a	a	a	a	a	a	a
	30	252	185110	272915	a	121686	a	579711	a	116521	a	696232	a
		452		330215	a	138021	a	653346	a	116325	a	769671	a
		652		387585	a	153973	a	726668	a	116301	a	842969	a
	160	252	185110	a	a	a	a	a	a	a	a	a	a
		452		a	a	a	a	a	a	a	a	a	a
		652		a	a	a	a	a	a	a	a	a	a
400000	0	252	185110	272915	214362	127561	89161	585586	488653	116485	118357	702071	607004
		452		330215	289662	137693	92220	653018	566992	116224	118473	769242	485465
		652		a	a	a	a	a	a	a	a	a	a
	80	252	185110	272915	228507	127534	110727	585559	524344	116402	129811	701961	654155
		452		330215	303789	143869	113940	659194	602839	116173	129912	775367	732751
		652		387585	379070	159820	117510	732515	681690	116198	130014	848693	811704
	160	252	185110	a	242636	a	126414	a	554160	a	139305	a	693465
		452		a	317917	a	123285	a	626312	a	139421	a	765733
		652		a	393198	a	131878	a	710186	a	139735	a	849921

a Not Simulated

TABLE 6.7

TOTAL SYSTEM COSTS AND ITS COMPONENTS FOR A STANDARD RATE TRICKLING FILTERS TREATMENT PLANT ASSOCIATED WITH ALTERNATIVE COLLECTION SYSTEMS AND SPRINKLER IRRIGATION OF VEGETATION STRATEGY 1 AT VARIOUS ASSUMED RATES OF DEVELOPMENTS AT WHITE RIVER LAKE, TEXAS

Capacity of Effluent Storage (Gallons)		Number of Vacation Homes in 1994	F(I): Fixed Cost for Irrigation System (Dollars)	F(C): Fixed Cost for Collection System (Dollars)		F(T): Fixed Cost for Treatment (Dollars)		T(F): Total Fixed Cost (Dollars)		T(O): Total Operation and Maintenance Cost (Dollars)		T(S): Total System Cost (Dollars)	
				Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure
		252		272915	214382	182935	133850	640960	533342	122949	124407	763909	657749
	0	452	185110	330215	289662	200512	139233	715837	614005	122781	124344	838618	738349
		652		a	364941	a	144515	a	694566	a	124332	a	818898
		252		272915	a	198935	a	656968	a	121204	a	778164	a
80000	80	452	185110	330215	303789	225172	171316	740497	660215	121106	136602	861603	796817
		652		387585	379070	250046	176631	822741	740811	121989	136677	943730	877488
		252		272915	242636	214210	197112	672235	624858	123091	146211	818446	771069
	160	452	185110	330215	317917	240447	201577	755772	704604	122942	146320	878714	850924
		652		387585	393198	265321	205994	838016	784302	123117	146674	961133	930976
		252		272915	a	191923	a	a	a	a	a	a	a
	0	452	185110	330215	a	209500	a	a	a	a	a	a	a
		652		a	a	a	a	a	a	a	a	a	a
		252		272915	a	207923	a	665948	a	121081	a	787029	a
200000	80	452	185110	330215	a	234160	a	749485	a	121064	a	870549	a
		652		387585	a	259034	a	831729	a	121873	a	953602	a
		252		a	a	a	a	a	a	a	a	a	a
	160	452	185110	a	a	a	a	a	a	a	a	a	a
		652		a	a	a	a	a	a	a	a	a	a
		252		272915	214382	197770	148685	655795	548177	122935	124392	778730	672569
	0	452	185110	330215	289662	215347	154068	730672	628840	122682	124313	853354	753153
		652		a	a	a	a	a	a	a	a	a	a
		252		272915	228507	213770	180123	671795	593740	121192	136595	792987	730335
400000	80	452	185110	330215	303789	240007	186151	755332	675050	121018	136571	876350	811621
		652		387585	379070	264881	191466	837576	755646	121888	136612	959464	892258
		252		a	242636	a	211947	a	639693	a	146201	a	785894
	160	452	185110	a	317917	a	216412	a	719439	a	146641	a	866080
		652		a	393198	a	220829	a	799137	a	146684	a	945821

[a]Not Simulated

TABLE 6.8

TOTAL SYSTEM COSTS AND ITS COMPONENTS FOR AN ACTIVATED SLUDGE TREATMENT PLANT ASSOCIATED WITH ALTERNATIVE COLLECTION METHODS AND SPRINKLER IRRIGATION OF VEGETATION STRATEGY 1 AT VARIOUS ASSUMED RATES OF DEVELOPMENTS AT WHITE RIVER LAKE, TEXAS

Capacity of Effluent Storage (Gallons)		Number of Vacation Homes in 1994	F(I): Fixed Cost For Irrigation System (dollars)	F(C): Fixed Cost for Collection System (Dollars)		F(T): Fixed Cost for Treatment (Dollars)		T(F): Total Fixed Cost (Dollars)		T(O): Total Operation and Maintenance Cost (Dollars)		T(S): Total System Cost (Dollars)	
				Gravity	Pressure	Gravity	Prussure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure
		252		272915	214382	218999	149260	677024	548752	122311	124513	799335	673265
	0	452	185110	330215	289662	245701	156215	761026	630987	122238	124421	883264	755408
		652		a	364949	a	163066	a	713117	a	124506	a	837623
80000		252		272915	a	234999	a	693024	a	120792	a	813816	a
	80	452	185110	330215	303789	270361	198944	785686	687843	120715	136443	906401	824286
		652		387585	379070	304204	205255	876389	760435	120702	136510	997601	905945
		252		272915	242636	250012	232555	708037	660301	122527	146233	830564	806534
	160	452	185110	330215	317917	294115	238542	809440	741569	122504	146325	931944	887894
		652		387585	393198	327958	244475	900653	822783	122510	146824	1023163	969607
		252		a	a	a	a	a	a	a	a	a	a
	0	452	185110	a	a	a	a	a	a	a	a	a	a
		652		a	a	a	a	a	a	a	a	a	a
200000		252		272915	a	243987	a	702012	a	120655	a	822667	a
	80	452	185110	330215	a	279349	a	794674	a	120614	a	915288	a
		652		387585	a	313192	a	885887	a	120662	a	1006549	a
		252		a	a	a	a	a	a	a	a	a	a
	160	452	185110	a	a	a	a	a	a	a	a	a	a
		652		a	a	a	a	a	a	a	a	a	a
		252		272915	214382	233834	164095	691859	563567	122192	124213	814051	687800
	0	452	185110	330215	289662	260536	171050	775861	645822	122141	124179	898002	770001
		652		a	a	a	a	a	a	a	a	a	a
		252		272915	228507	249834	208468	707859	622085	120512	136321	828371	758406
400000	80	452	185110	330215	303789	285196	213779	800521	702678	120572	136272	921093	838950
		652		387585	379070	319040	220090	891735	784270	120515	136469	1012250	920739
		252		a	242636	a	247390	a	675136	a	146227	a	821563
	160	452	185110	a	317917	a	253377	a	756404	a	146219	a	902623
		652		a	393198	a	259310	a	837618	a	146712	a	984330

[a]Not Simulated

TABLE 6.9

TOTAL SYSTEM COST AND ITS MAJOR COMPONENTS FOR PACKAGE TREATMENT PLANT ASSOCIATED WITH ALTERNATIVE COLLECTION METHODS AND SPRINKLER IRRIGATION OF VEGETATION STRATEGY 1 AT VARIOUS ASSUMED RATES OF DEVELOPMENTS AT WHITE RIVER LAKE, TEXAS

Capacity of Effluent Storage (gallons)		Number of Vacation Homes in 1994	F(I): Fixed Costs for Irrigation & Vegetation (dollars)	F(C): Fixed Costs for Collection System (dollars)		F(T): Fixed Costs for Treatment (dollars)		T(F): Total Fixed Cost (dollars)		T(O): Total O&M Cost (dollars)		T(S): Total System Cost (dollar)	
				Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure
		252		272925	214382	95072	75779	552097	475471	129498	131680	682595	607151
	0	452	185110	330215	289662	100353	78910	615678	553682	129305	131650	744983	685332
		652		a	364941	a	81782	a	631833	a	133695	a	763528
		252		272915	a	111072	a	569097	a	120735	a	689832	a
80000	80	452	185110	330215	303789	124953	96569	640278	585468	126637	142843	766915	728311
		652		387585	379070	138132	99131	710827	663311	126426	142817	837253	806128
		252		272915	242636	126951	110100	584976	537846	129634	151548	708670	689394
	160	452	185110	330215	317917	147912	112482	663237	615509	129472	141901	792701	767410
		652		387585	393198	161057	114834	733752	693142	129920	152189	863672	845331
		252		a	a	a	a	a	a	a	a	a	a
	0	452	185110	a	a	a	a	a	a	a	a	a	a
		652		a	a	a	a	a	a	a	a	a	a
		252		272915	a	120060	a	578085	a	120612	a	698697	a
200000	80	452	185110	330215	a	133941	a	649266	a	126595	a	775861	a
		652		387585	a	147120	a	719815	a	126310	a	846125	a
		252		a	a	a	a	a	a	a	a	a	a
	160	452	185110	a	a	a	a	a	a	a	a	a	a
		652		a	a	a	a	a	a	a	a	a	a
		252		272915	214382	109907	90814	567932	490306	129512	131500	697444	621806
	0	452	185110	330215	289662	115188	93745	630513	568517	129204	131512	759717	700029
		652		a	a	a	a	a	a	a	a	a	a
		252		272915	228507	126907	108462	583932	522079	120531	142793	704463	664872
400000	80	452	185110	330215	303789	139788	111404	655113	600303	126237	142751	781550	743054
		652		387585	379070	152967	114766	725662	678946	126253	142712	851915	821658
		252		a	242636	a	124935	a	552681	a	151837	a	704518
	160	452	185110	a	317917	a	127317	a	630344	a	152322	a	782666
		652		a	393198	a	129669	a	707977	a	152104	a	860081

[a]Not Simulated

TABLE 6.10

TOTAL SYSTEM COST AND ITS COMPONENTS FOR A HIGH RATE TRICKLING PLANT AND STABILIZATION POND ASSOCIATED WITH ALTERNATIVE COLLECTION METHODS AND SUBMATIC IRRIGATION OF VEGETATION STRATEGY 1 AT VARIOUS ASSUMED RATES OF DEVELOPMENTS AT WHITE RIVER LAKE, TEXAS

Capacity of the Effluent Storage (gallons)		Number of Vacation Homes in 1994	F(I): Fixed Cost for Irrigation System (dollars)	F(C): Fixed Cost for Collection System (dollars)		F(T): Fixed Cost for Treatment (dollars)		T(F): Total Fixed Cost (dollars)		T(O): Total O&M Cost (dollars)		Total System Cost: T(S) (dollars)	
				Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure
	0	252		272915	214382	206985	149263	542229	425974	131561	134199	673790	560173
		452	62329	330215	289662	227860	155348	620404	507339	130452	134099	750856	541438
		652		a	364941	a	161383	a	588653	a	134082	a	722735
		252		272915	a	222986	a	558230	a	136856	a	695086	a
80000	80	452	62329	330215	303789	252520	192400	645064	558518	136379	146334	781443	704852
		652		387585	379070	280423	197791	730337	639190	136864	146243	867201	785433
		252	62329	272915	242636	237750	220928	572994	525893	141883	161289	714877	687184
	160	452		330215	317917	267204	225946	659748	606192	142000	161561	801748	767753
		652		387585	393198	295182	230942	745096	686469	142212	161771	887308	848240
		252		a	214382	a	158251	a	434962	a	134161	a	569131
	0	452	62329	a	289162	a	164336	a	516327	a	134019	a	650346
		652		a	364941	a	170371	a	597641	a	133879	a	731520
		252		272915	a	231974	a	567218	a	136825	a	704043	a
200000	80	452	62329	330215	a	261508	a	654052	a	136315	a	790367	a
		652		387585	a	289411	a	739325	a	136772	a	876097	a
		252		272915	242636	231973	229916	567217	534881	141862	161270	709079	696151
	160	452	62329	330215	317917	276192	234934	668736	615180	141942	161506	810678	776686
		652		387585	393198	304170	239930	754084	695457	142104	161663	896188	857120
		252		272915	214382	221820	164098	557064	440809	131522	134159	688586	574968
	0	452	62329	330215	289662	242695	170183	635239	522174	130629	134064	765868	656238
		652		387585	364941	268730	176218	718644	603488	130751	134021	849395	737509
		252		272915	a	237821	a	573065	a	136687	a	709752	a
400000	80	452	62329	330215	a	267315	a	659899	a	136288	a	796187	a
		652		387585	a	295258	a	745772	a	136123	a	881895	a
		252		272915	242636	237820	235764	587229	540729	141853	161261	729682	701990
	160	452	62329	330215	317917	282039	249782	683571	621028	141948	161031	825519	782059
		652		387585	393198	310017	245777	768919	701304	141496	161055	910415	862359

[a]Not Simulated

TABLE 6.11

TOTAL SYSTEM COST AND ITS COMPONENTS FOR A STANDARD RATE TRICKLING FILTERS PLANT AND STABILIZATION POND ASSOCIATED WITH ALTERNATIVE COLLECTION SYSTEMS AND SUBMATIC IRRIGATION OF VEGETATION STRATEGY 1, AT VARIOUS ASSUMED DEVELOPMENTS AT WHITE RIVER LAKE, TEXAS

Capacity of Effluent Storage		Number of Vacation Homes in 1994	F(I): Fixed Cost for Irrigation and Vegetation (dollars)	F(C): Fixed Cost for Collection System (dollars)		F(T): Fixed Cost for Treatment (dollars)		T(F): Total Fixed Cost (dollars)		T(O): Total O&M Cost (dollars)		T(S): Total System Cost (dollars)	
				Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure
80000	0	252	62329	272915	214382	240971	174327	576215	451038	132401	135157	708616	586195
		452		330215	289662	265377	181203	657921	533194	131350	135052	789271	668246
		652		a	364941	a	187939	a	615209	a	135029	a	750238
	80	252	62329	272915	a	256971	a	592215	a	137687	a	729902	a
		452		330215	303789	290037	222167	682581	588285	137210	147218	819791	735503
		652		387585	379070	321287	228757	771201	670156	137662	147120	908823	817276
	160	252	62329	272915	242636	273972	254667	609216	559632	142652	162110	751868	721742
		452		330215	317917	307035	260305	699579	640551	142765	162372	842344	802923
		652		387585	393198	338292	265879	788206	721406	143913	162574	932119	883980
200000	0	252	62329	a	214382	a	183315	a	460026	a	135119	a	595145
		452		a	289662	a	190191	a	542182	a	134972	a	677154
		652		a	364941	a	196297	a	624197	a	134826	a	759023
	80	252	62329	272915	a	265959	a	601203	a	137647	a	738850	a
		452		330215	a	299025	a	691569	a	137142	a	828711	a
		652		387585	a	330275	a	780189	a	137515	a	917704	a
	160	252	62329	272915	242636	282960	263655	618204	568620	142659	162089	760863	730709
		452		330215	317917	316023	269293	708567	649539	142731	162317	851298	811856
		652		387585	393198	347280	274867	797194	730394	143876	162466	941070	892860
400000	0	252	62329	272915	214382	255806	189222	591050	465873	132361	135117	723311	600990
		452		330215	289662	280212	196038	672756	548029	131173	135017	803929	683046
		652		387585	364941	303630	202774	753544	630044	131138	134968	884682	765012
	80	252	62329	272915	a	271806	a	607050	a	137641	a	744691	a
		452		330215	a	304872	a	697416	a	137130	a	834546	a
		652		387585	a	336122	a	786036	a	137506	a	923542	a
	160	252	62329	272915	242636	288807	269502	624051	574467	142651	162080	766702	736547
		452		330215	317917	321870	275140	714414	655386	142722	162323	857136	817709
		652		387585	393198	353127	280714	803041	736241	143870	162458	946911	898699

[a]Not Simulated

TABLE 6.12

TOTAL SYSTEM COSTS AND ITS COMPONENTS FOR ACTIVATED SLUDGE TREATMENT PLANTS AND STABILIZATION POND ASSOCIATED WITH ALTERNATIVE COLLECTION METHODS AND SUBMATIC IRRIGATION OF VEGETATION STRATEGY 1, AT VARIOUS ASSUMED RATES OF DEVELOPMENTS AT WHITE RIVER LAKE, TEXAS

Capacity of Effluent Storage (Gallons)		Number of Vacation Homes in 1994	F(I): Fixed Cost for Irrigation System (Dollars)	F(C): Fixed Cost for Collection System (Dollars)		F(T): Fixed Cost for Treatment (Dollars)		T(F): Total Fixed Cost (Dollars)		T(O): Total Operation and Maintenance Cost (Dollars)		T(S): Total System Cost (Dollars)	
				Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure
		252		272915	214382	277035	189737	612279	466448	132111	134536	744390	600984
	0	452	62329	330215	289662	310566	198185	703110	550176	131639	134462	834149	684638
		652		a	364941	a	206490	a	633760	a	134474	a	768234
		252		272915	a	293035	a	628279	a	137542	a	765821	a
80,000	80	452	62329	330215	303789	335226	249795	727770	615913	137035	146984	864805	762897
		652		387585	379070	375439	257381	825353	698780	137482	146921	962835	845701
		252		272915	242636	308021	290110	643265	595075	142981	162205	786246	757280
	160	452	62329	330215	317917	352215	297270	744759	677516	143712	162499	888471	840015
		652		387585	393198	392419	304360	842333	759887	143921	162740	986254	922627
		252		a	214382	a	198725	a	475436	a	134492	a	609928
	0	452	62329	a	289662	a	207173	a	559164	a	134415	a	693579
		652		a	364941	a	215478	a	642748	a	134441	a	777189
		252		272915	a	302023	a	637267	a	137517	a	774784	a
200,000	80	452	62329	330215	a	344214	a	753747	a	136994	a	890741	a
		652		387585	a	484427	a	851321	a	137410	a	988731	a
		252		272915	242636	317009	299098	652252	604063	142942	162178	795796	766241
	160	452	62329	330215	317917	361203	306258	752747	686504	143665	162435	897412	848939
		652		387585	393198	401407	313348	851321	768875	143851	162687	995172	931562
		252		272915	214382	291870	204572	627114	481282	132005	162193	759119	643476
	0	452	62329	330215	289662	325401	213020	717945	565605	131524	162475	849469	728080
		652		387585	364941	358105	221325	809019	648595	132751	162701	940770	811296
		252		272915	a	307870	a	643114	a	135492	a	778606	a
400,000	80	452	62329	330215	a	350061	a	742605	a	136951	a	879556	a
		652		387585	a	390274	a	840188	a	137295	a	977583	a
		252		272915	242636	323036	313933	658280	618898	142912	162169	801192	781067
	160	452	62329	330215	317917	367050	321093	759594	701339	143615	162431	903209	863770
		652		387585	393198	407254	328183	857168	783710	143813	162678	1000981	946388

[a]Not Simulated

TABLE 6.13

TOTAL SYSTEM COSTS AND ITS COMPONENTS FOR A PACKAGE TREATMENT PLANT AND STABILIZATION POND ASSOCIATED WITH ALTERNATIVE COLLECTION METHODS AND SUBMATIC IRRIGATION OF VEGETATION STRATEGY 1 AT VARIOUS ASSUMED RATES OF DEVELOPMENTS AT WHITE RIVER LAKE, TEXAS

Capacity of Effluent Storage (gallons)	Number of Vacation Homes in 1994	F(I) : Fixed Cost for Irrigation Vegetation System (dollars)	F(C): Fixed Costs for Collection System		F(T): Fixed Cost for Irrigation System		T(F): Total Fixed Cost		T(O):Total O&M Cost		T(S):Total System Cost	
			Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure
	252		272915	214382	153108	116456	488352	393167	139040	142430	627392	535597
	452	62329	330215	289662	165218	120880	557762	472871	137874	142358	695636	615229
	652		a	364941	a	125206	a	552476	a	142225	a	694701
80000	252		272915	a	169108	a	504352	a	143218	a	647570	a
	452	62329	330215	303789	189878	147420	582522	513538	142741	153459	725163	745916
	652		387585	379070	209367	151257	659281	592656	143059	153260	802340	745916
	252		272915	242636	184122	167655	519366	472620	147387	167447	666753	640067
	452	62329	330215	317917	204815	171210	597359	551456	147561	167627	744920	719083
	625		387585	393198	224621	174719	674535	630246	147920	167736	822455	797982
	252		a	214382	a	125444	a	402155	a	142392	a	544547
	452	62329	a	289662	a	129868	a	481859	a	142278	a	624137
	652		a	364941	a	134194	a	561464	a	142022	a	703486
	252		272915	a	178096	a	513340	a	143272	a	656612	a
200000	452	62329	330215	a	198866	a	591410	a	142704	a	724114	a
	652		387585	a	218355	a	668269	a	142912	a	81181	a
	252		272915	252636	193110	176643	528854	481608	147345	167426	675699	649034
	452	62329	330215	397917	213803	180198	606347	560444	147510	167572	753857	728016
	652		387585	393198	233609	183707	683523	639234	147813	167628	831336	806862
	252		272915	214382	167943	131291	503187	408002	139000	142390	642187	550392
	452	62329	330215	289662	180053	135715	572597	487706	137697	142323	710294	630029
	652		387585	364941	184379	140041	634293	567311	137819	142164	772112	709475
	252		272915	a	183943	a	519187	a	143248	a	662435	a
400000	452	62329	330215	a	204713	a	597257	a	142681	a	739938	a
	652		387585	a	224202	a	674116	a	142803	a	816919	a
	252		272915	242636	198957	182490	534201	487455	147312	167417	681513	654872
	452	62329	330215	317917	219650	195033	612194	575279	147471	167566	759665	742845
	652		387585	393198	239466	198542	689380	654069	147752	167620	837132	821689

[a]Not Simulated

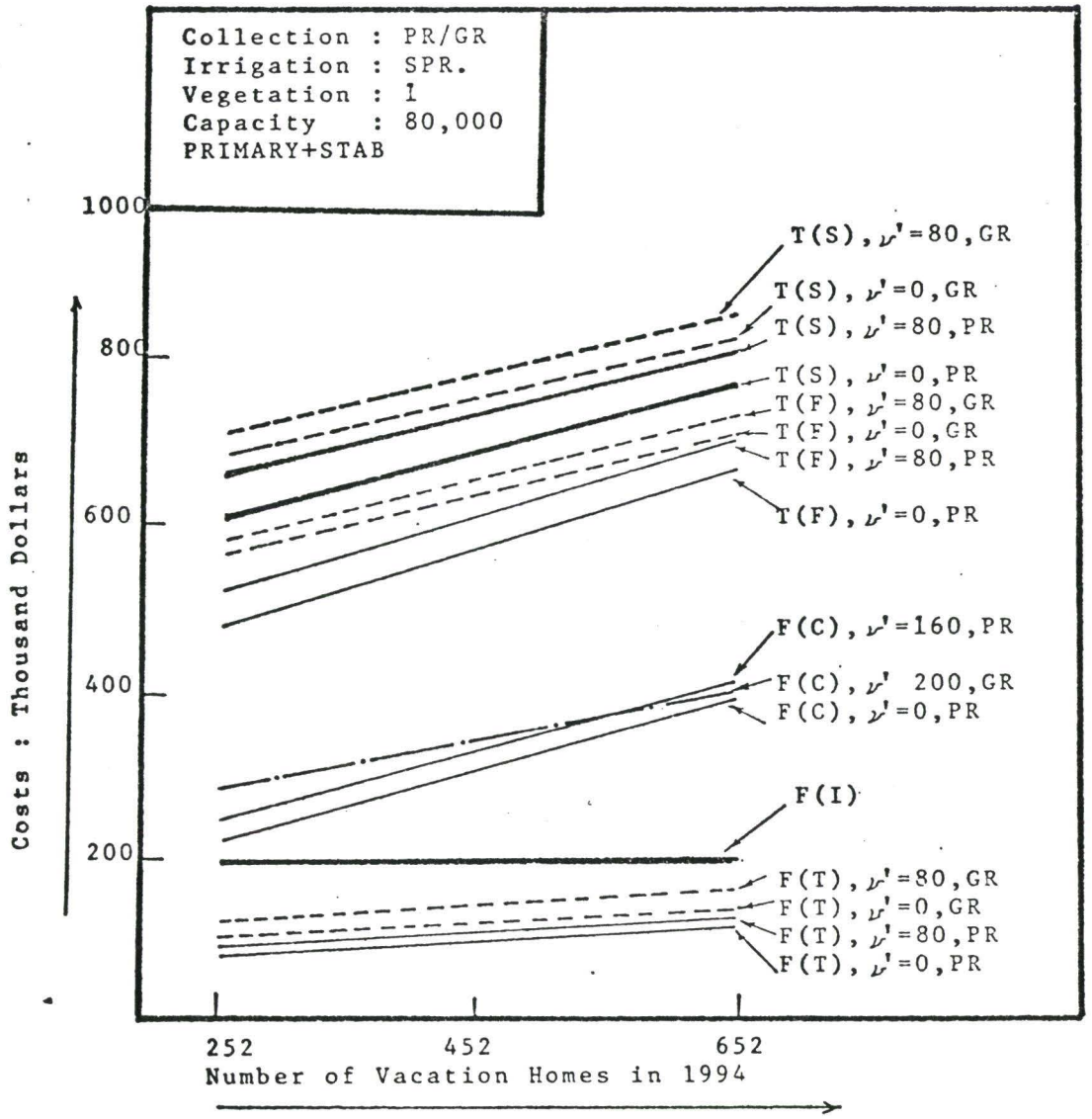

Figure 6.7. Components of fixed costs and total system costs for primary treatment plant along with a stabilization pond associated with alternative collection systems and sprinkler irrigation of vegetation strategy 1, at various assumed rates of developments at White River Lake, Texas.

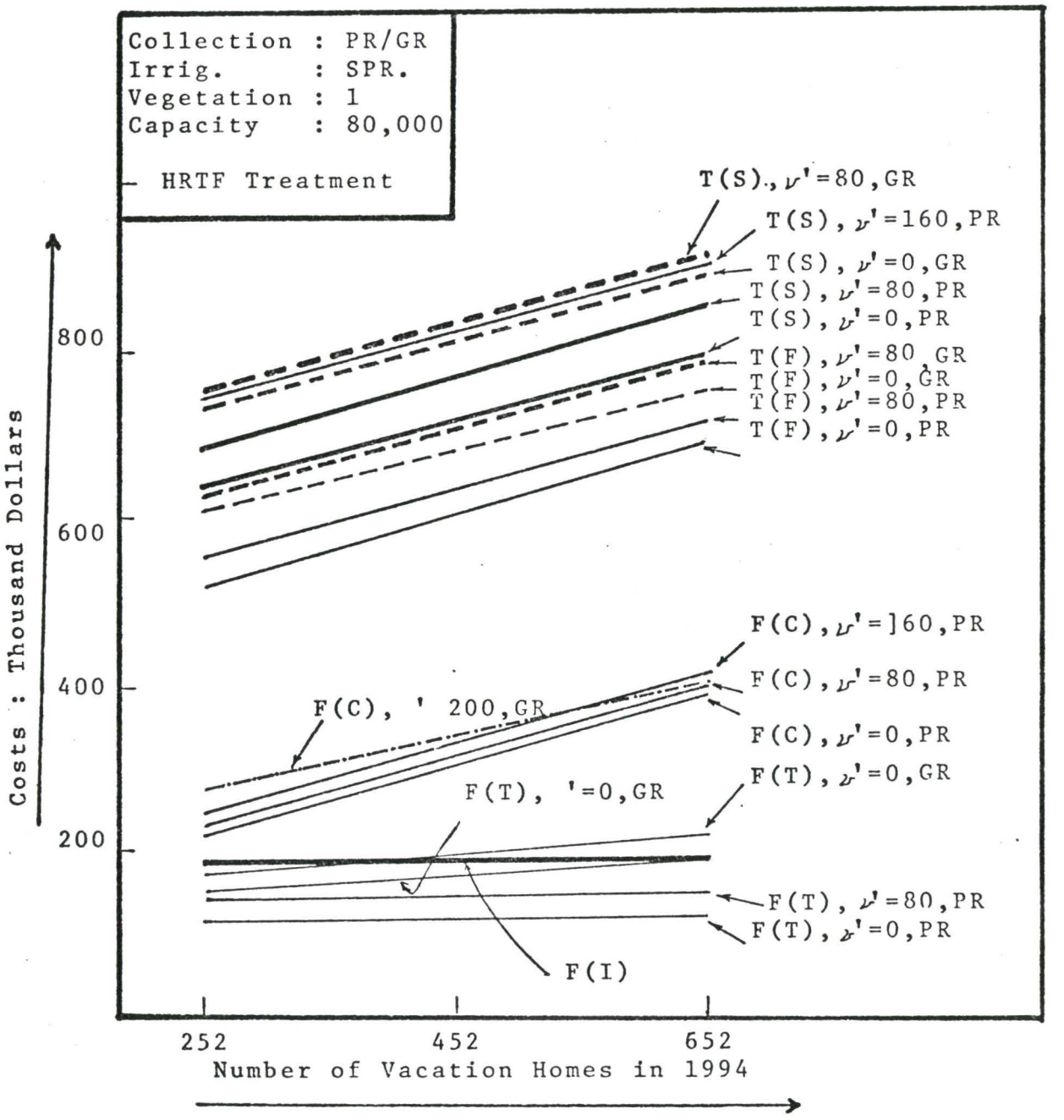

Figure 6.8. Various components of fixed cost and total systems costs for HRTF treatment plant associated with pressure or gravity collection systems, sprinkler irrigation, vegetation strategy 1, storage capacity 80,000 gallons at various assumed rates of developments at White River Lake, Texas.

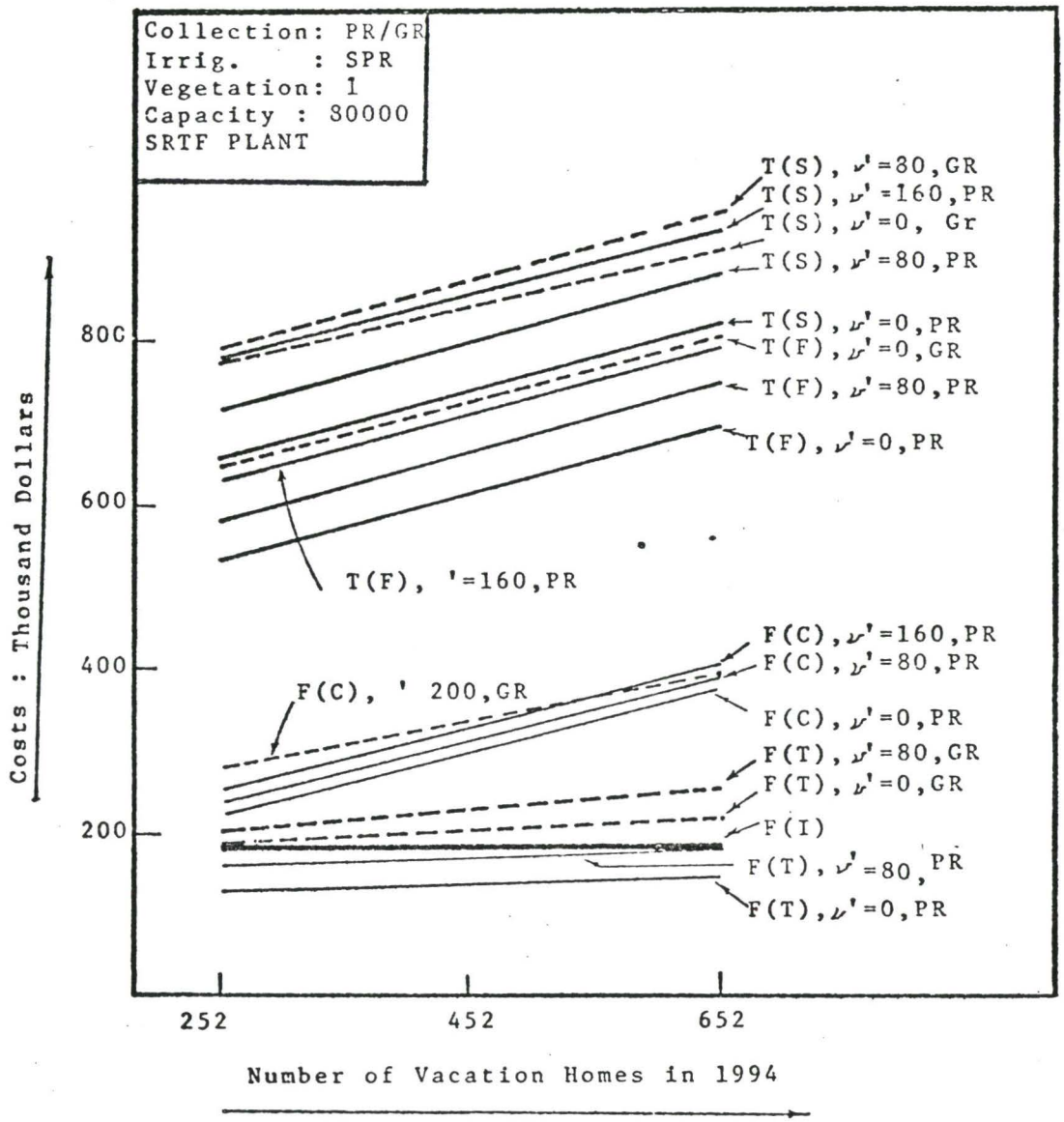

Figure 6.9. Various components of fixed costs and total system costs for SRTF treatment plant associated with alternative collection systems, sprinkler irrigation, vegetation strategy, effluent storage of capacity 80,000 gallons at various assumed rates of developments at White River Lake, Texas.

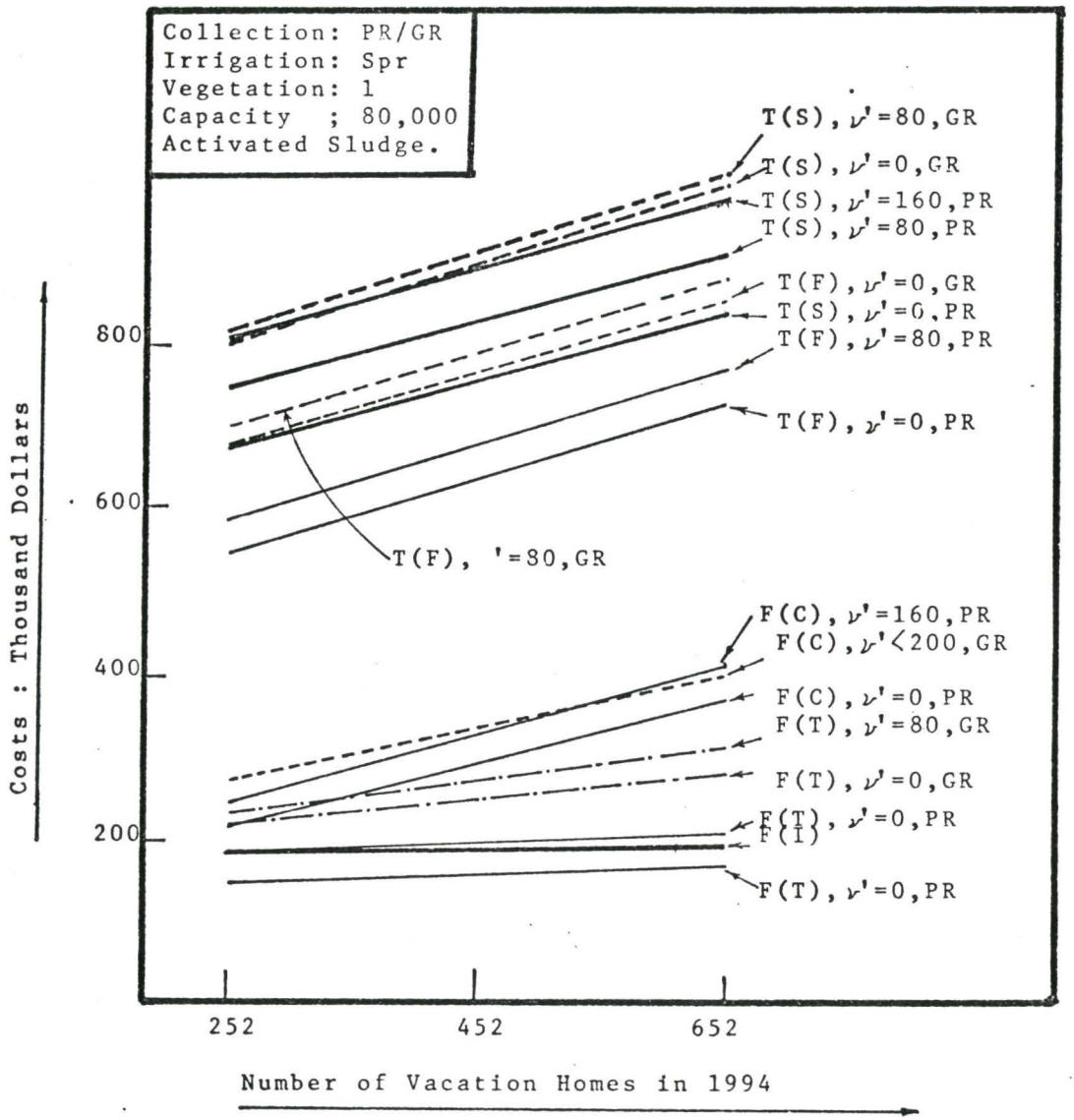

Figure 6.10. Various components of fixed costs and total systems costs of an activates sludge plant associated with pressure or gravity collection, sprinkler irrigation, vegetation strategy 1, at various assumed rates of developments at White River Lake, Texas.

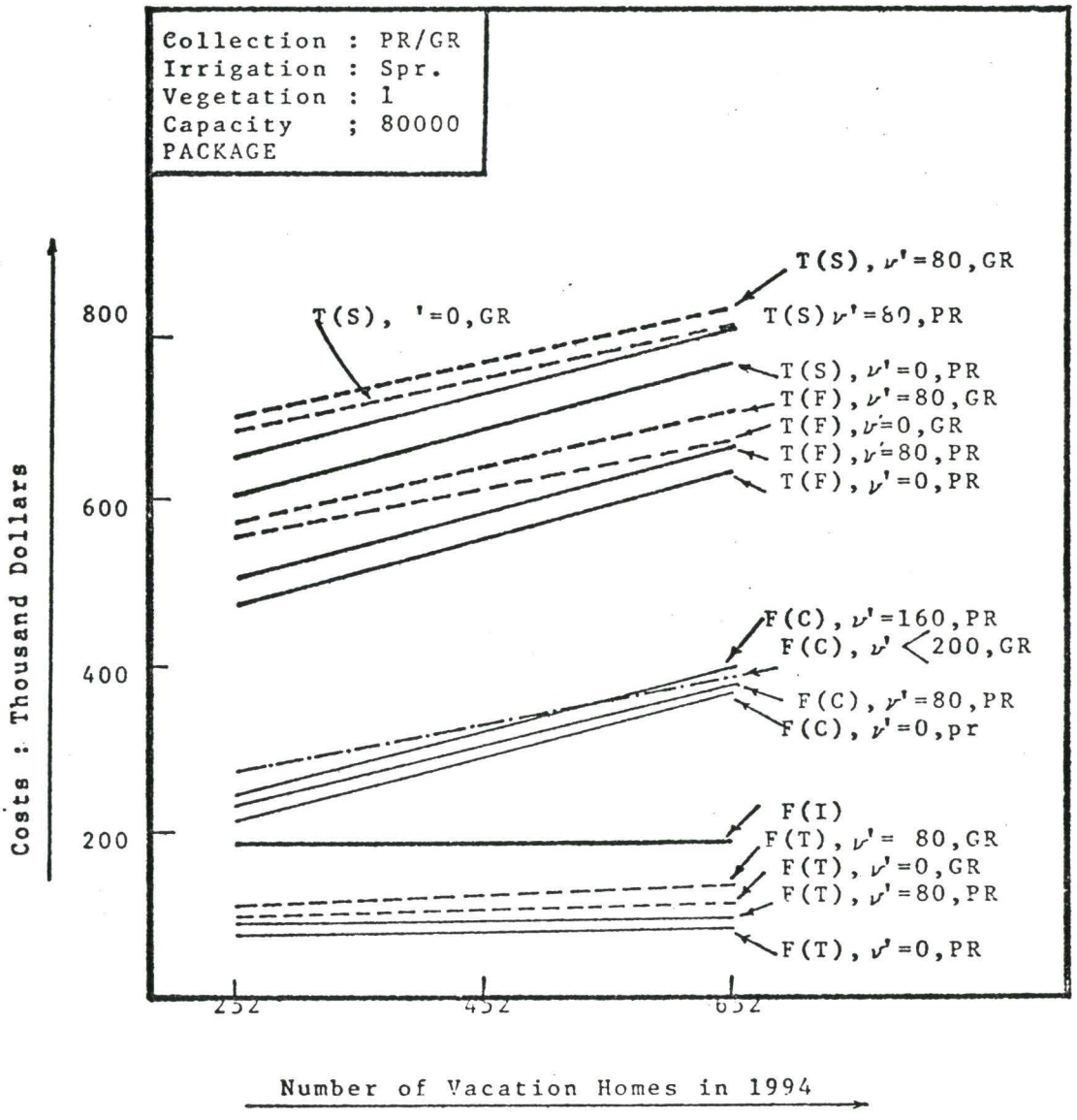

Figure 6.11. Components of fixed costs and total systems costs associated with a package treatment plant, gravity or pressure collection system, sprinkler irrigation of vegetation strategy 1 at various assumed rates of developments at White River Lake, Texas.

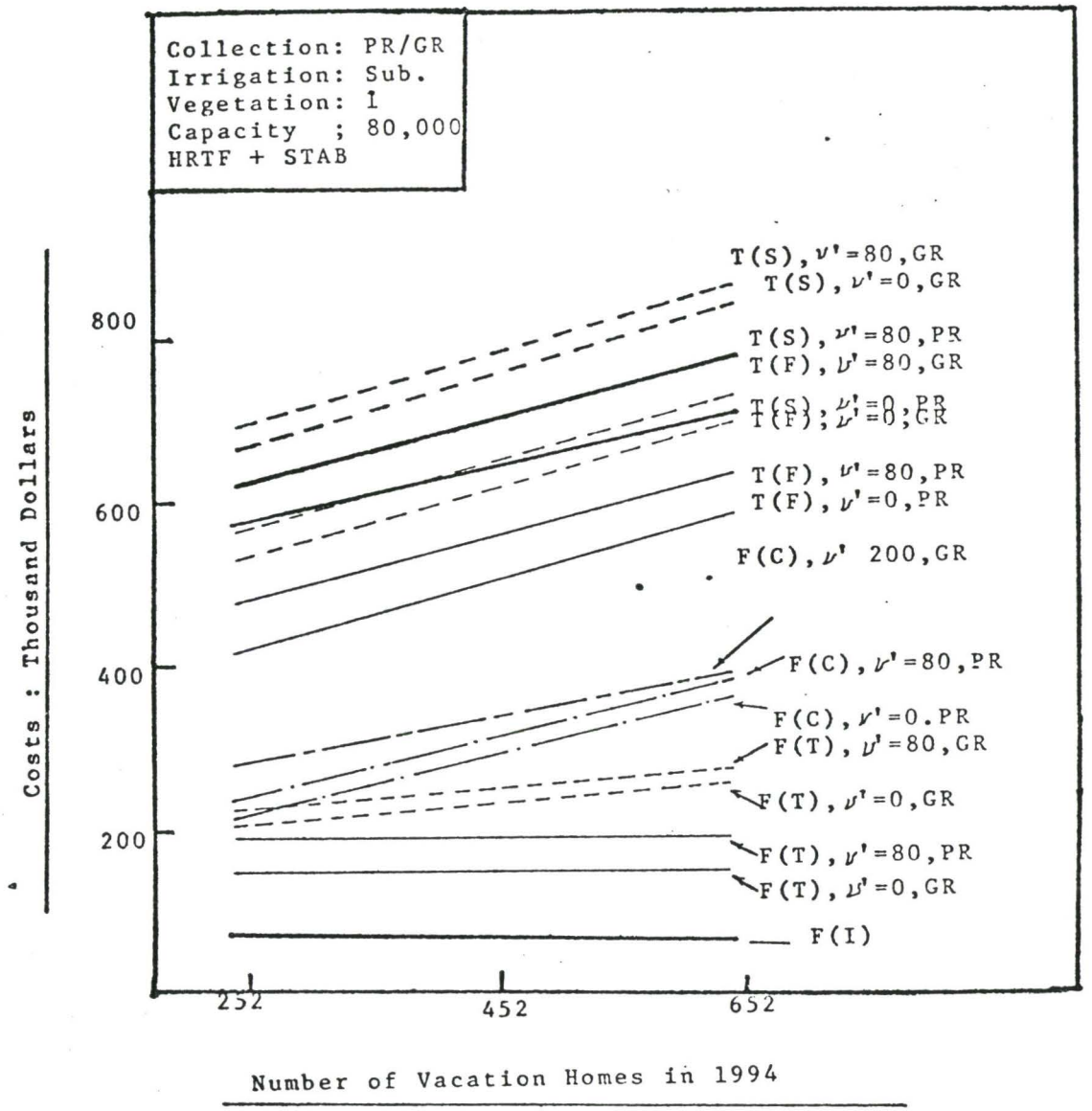

Figure 6.12. Components of fixed costs and total systems costs for HRTF plant and stabilization pond associated with pressure or gravity collection systems and submatic irrigation of vegetation strategy 1, at various assumed rates of developments at White River Lake, Texas.

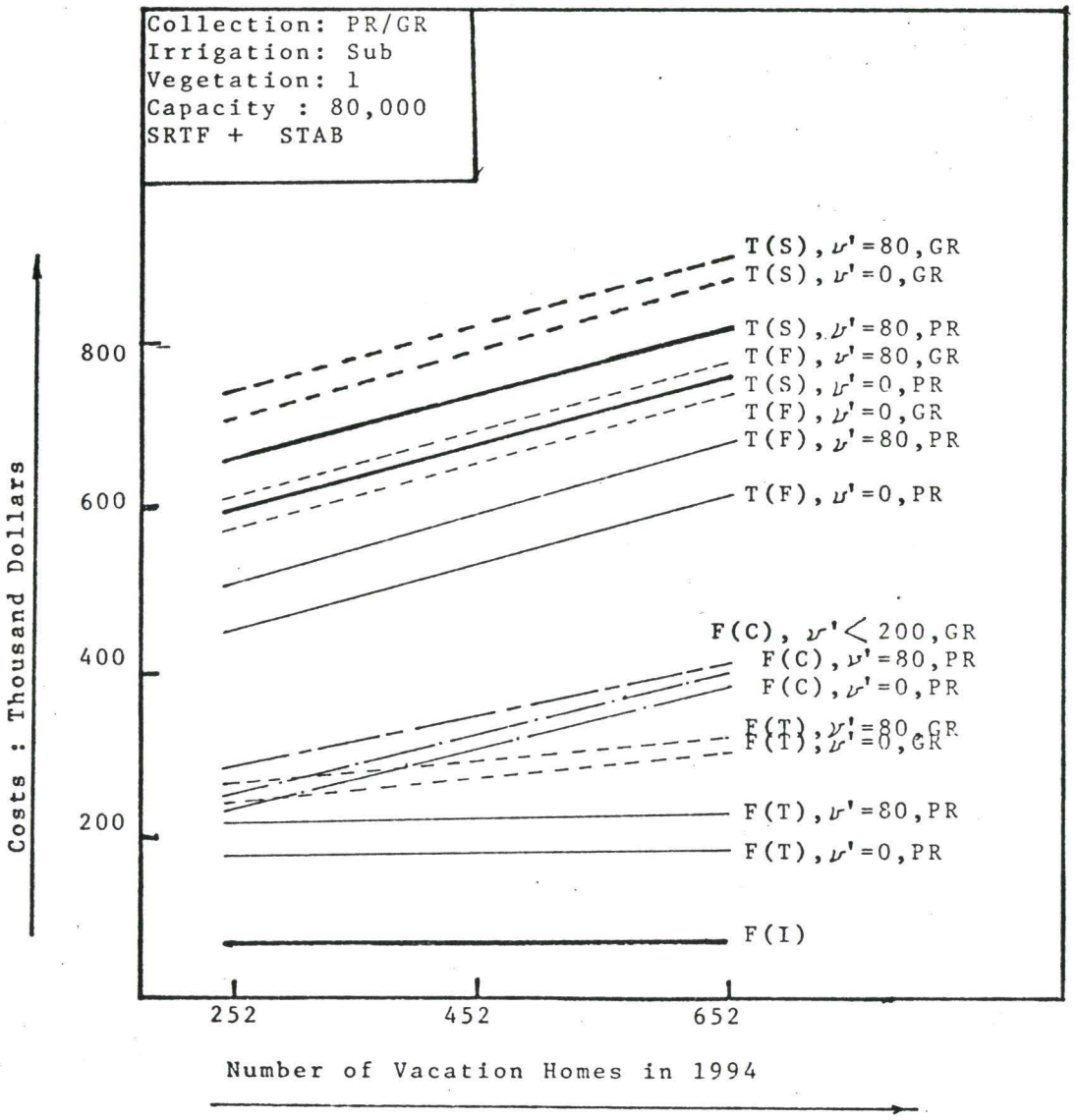

Figure 6.13. Components of fixed costs and total system costs for standard rate trickling filter and stabilization pond associated with pressure or gravity collection systems, and submatic irrigation of vegetation strategy 1, at various assumed rates of developments at White River Lake, Texas.

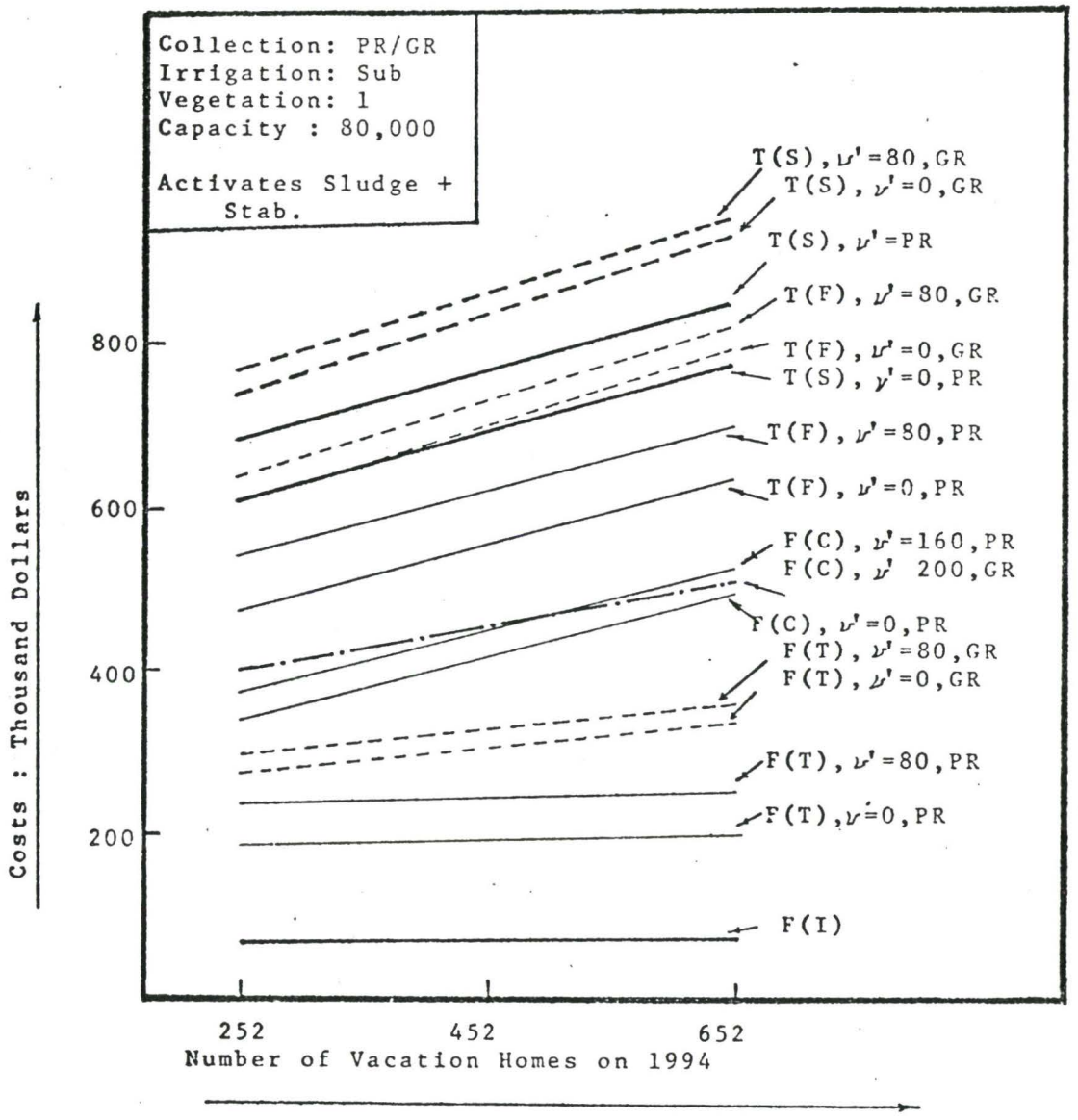

Figure 6.14. Components of fixed costs and total systems costs for activated sludge plant and stabilization pond associated with pressure or gravity collection systems, and submatic irrigation of vegetation strategy 1, at various assumed rates of developments at White River Lake, Texas.

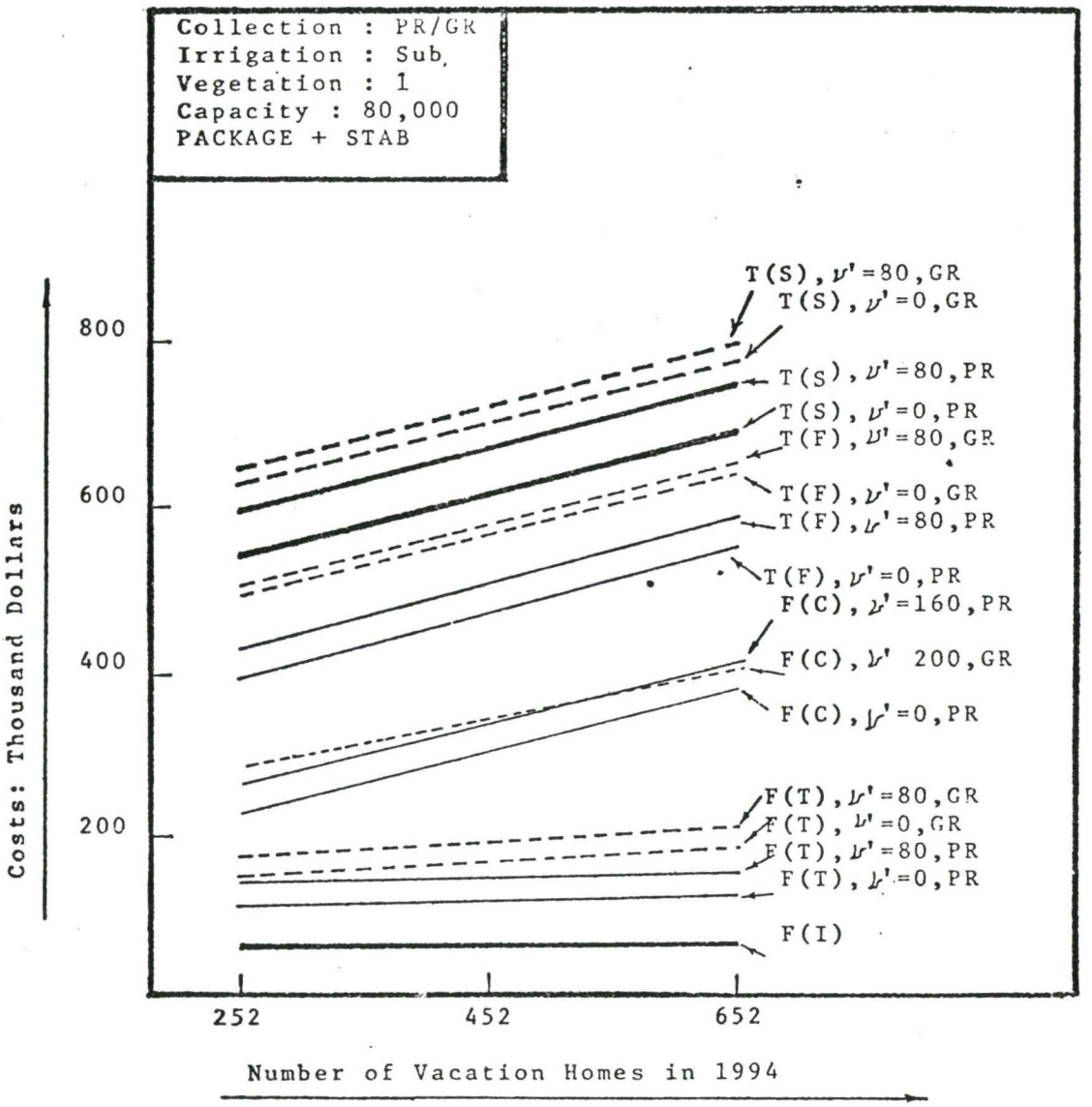

Figure 6.15. Components of fixed costs and total systems costs for a package plant and stabilization pond associated with gravity or pressure collection systems and submatic irrigation of vegetation strategy 1 at various assumed rates of developments at White River Lake, Texas.

These tables and figures illustrate one more important behavior of the system. They indicate that for any treatment plans being connected to a specific irrigation method, a system with pressure collection always has a lower system cost that a system with gravity collection for any assumed rate of development in the case study area.

Figures 6.16, 6.17, 6.18, and 6.19 show the total system costs for relatively low cost combinations of collection-treatment and irrigation alternatives for vegetation strategies 1, 2, 3 and 4, respectively. Figure 6.20 shows the cost characteristics of a central treatment plant which does not entail an irrigation vegetation system. Figure 6.15 shows that for any ν' and $(NC)_{1994}$, a pressure collection system associated with a package treatment plant and stabilization pond plus the submatic irrigation method constitutes the least system cost decision for vegetation strategy 1. A combination of pressure collection, high rate trickling filter, stabilization pond and submatic irrigation provides the second lowest system cost. All combinations of collection and treatment plants associated with sprinkler irrigation have considerably higher system costs. A combination of pressure collection, primary treatment and a stabilization pond has the lowest system cost for all possible combinations associated with sprinkler irrigation. However, this combination has a higher system cost than most of the combinations of collection and treatment alternatives associated with submatic irrigation. Hence,for vegetation strategy 1, a combination of pressure collection, a package plant and stabilization pond and submatic irrigation is undoubtedly the

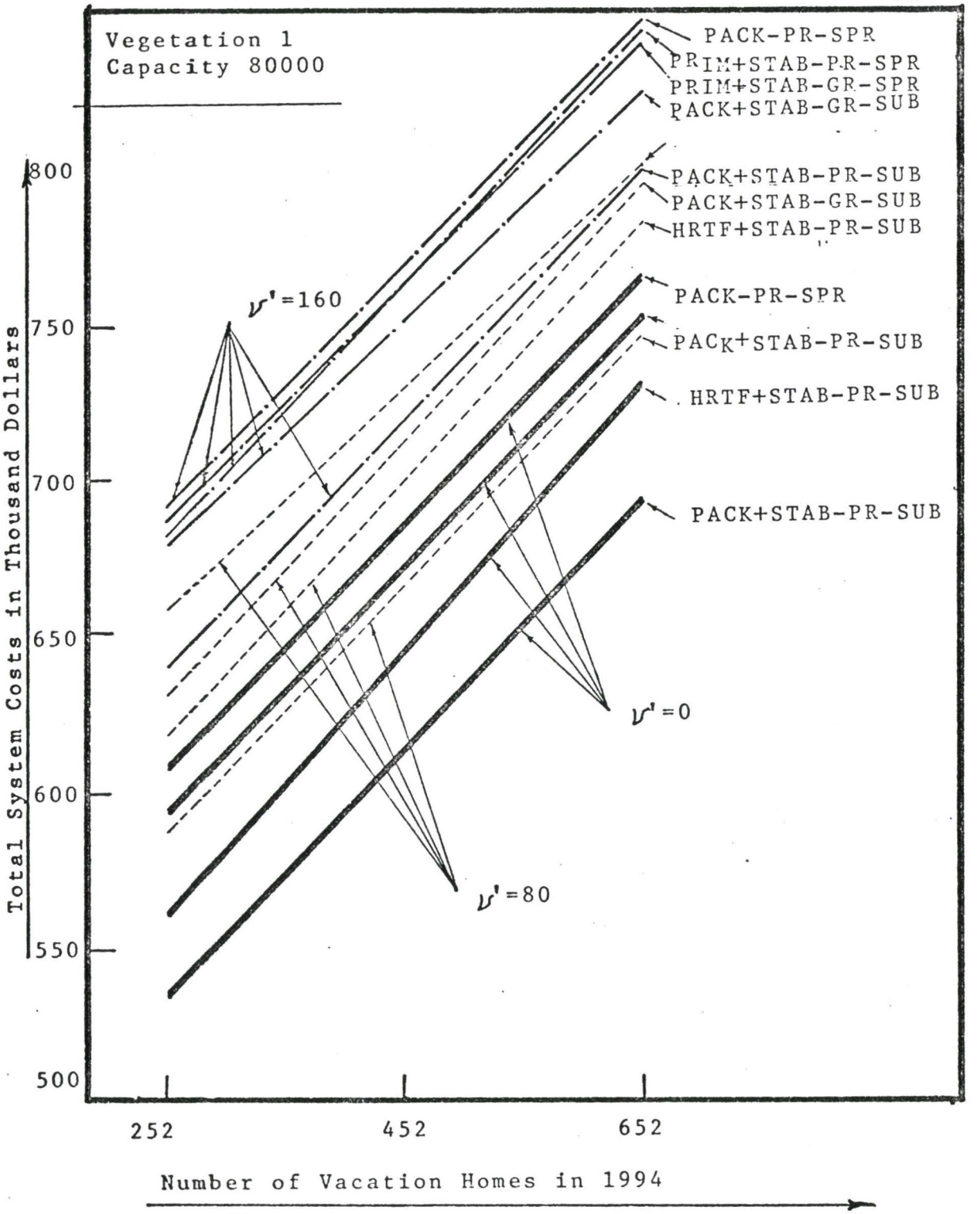

Figure 6.16. Total system cost for alternative collection-treatment and irrigation methods associated with vegetation strategy at various assumed rates of developments at White River Lake, Texas.

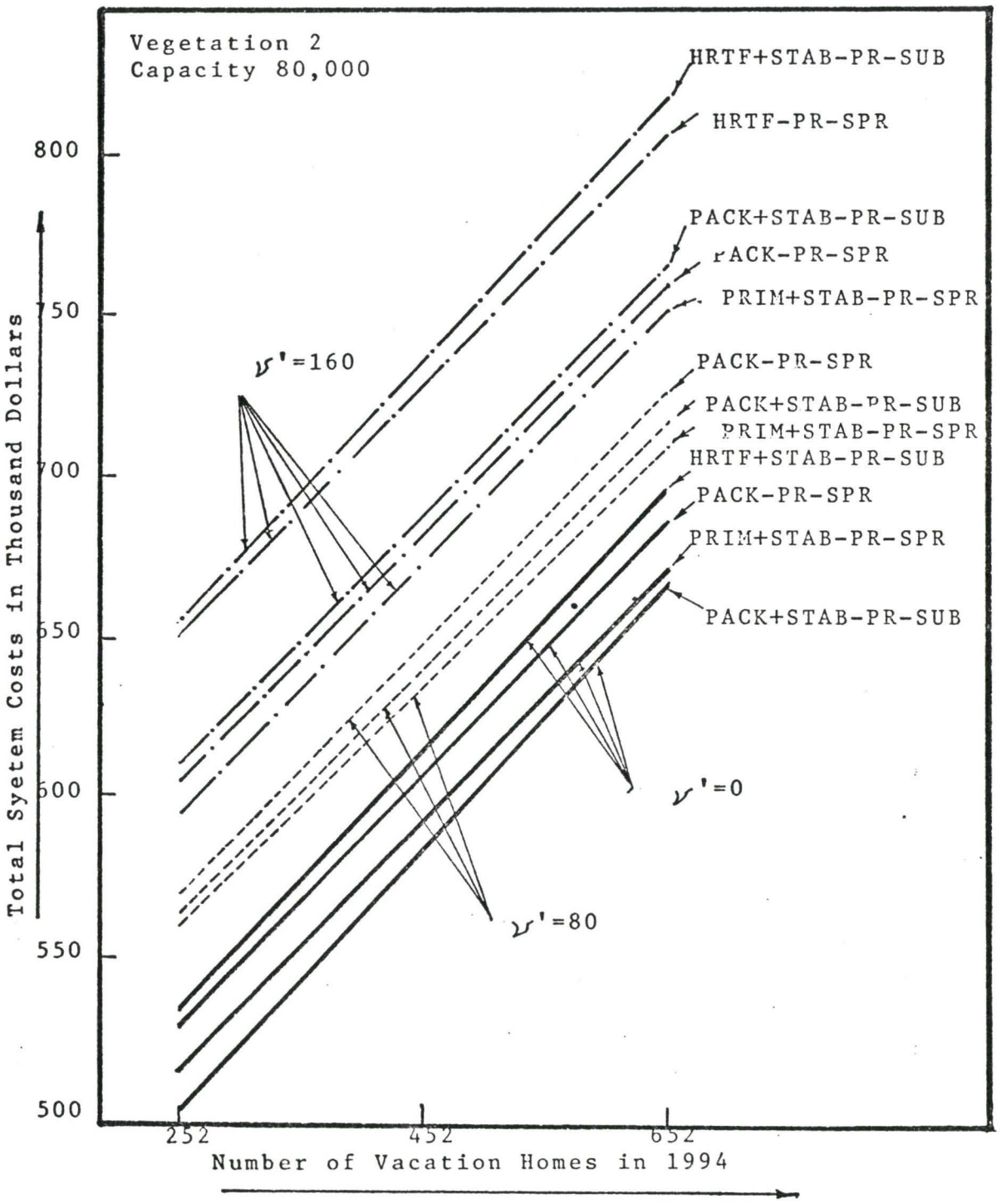

Figure 6.17. Total system costs for alternative collection-treatment and irrigation methods associated with vegetation strategy 2 at various assumed rates of developments at White River Lake, Texas.

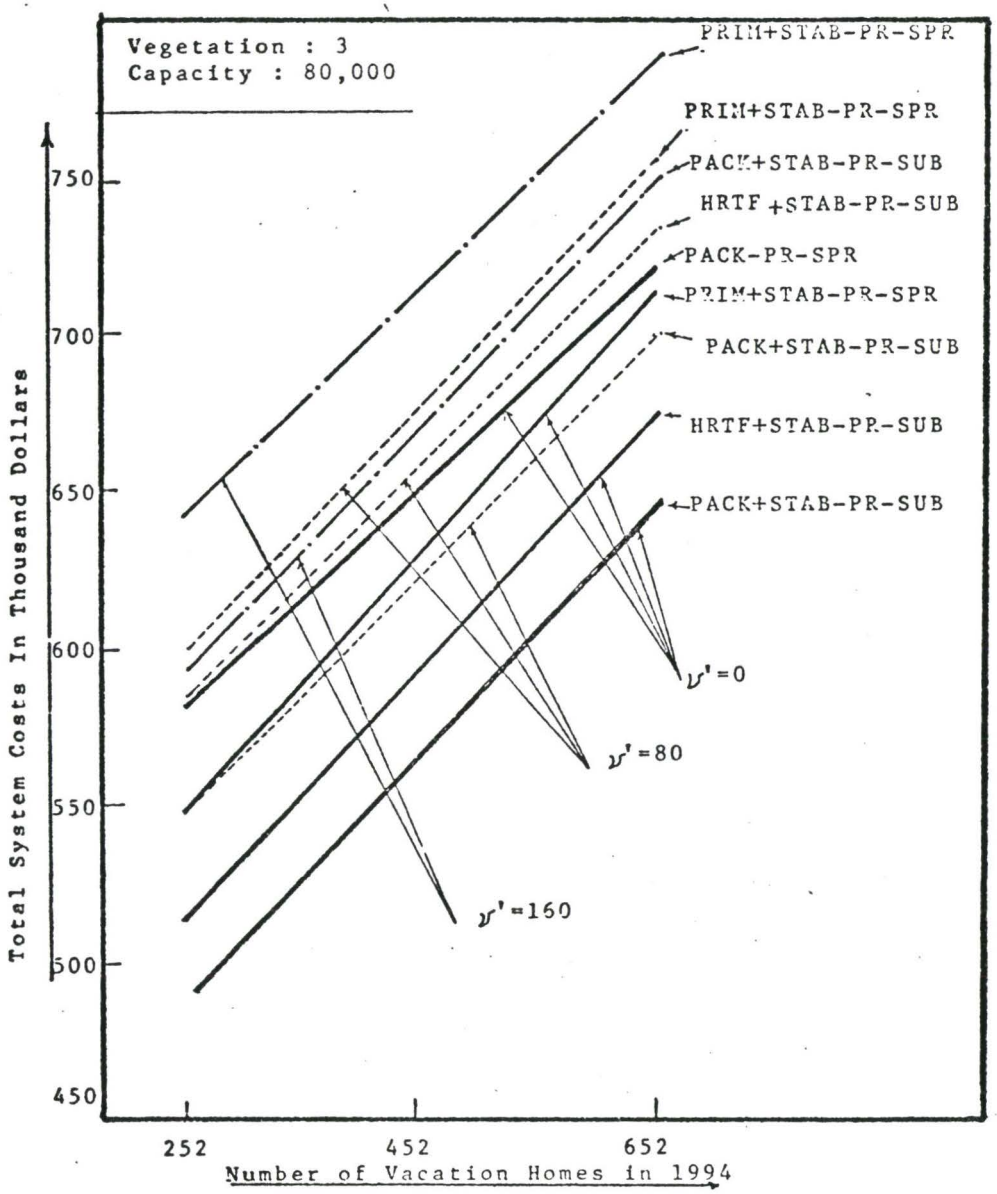

Figure 6.18. Total system costs for alternative collection-treatment and irrigation methods associated with vegetation strategy 3 at various assumed rate of development at White River Lake, Texas.

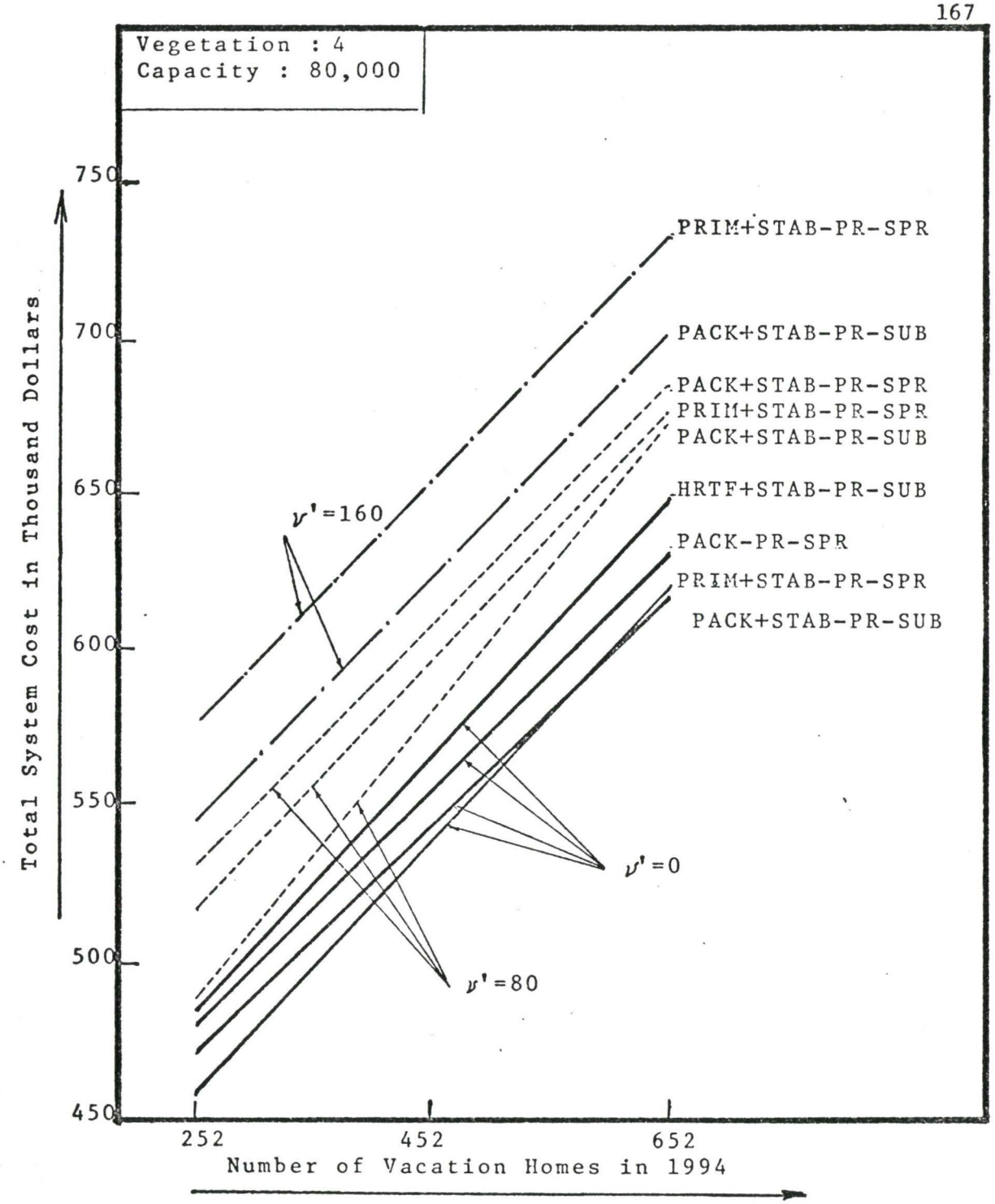

Figure 6.19. Total system cost for alternative collection-treatments and irrigation methods associated with vegetation strategy and effluent storage of 80,000 gallons at various assumed rates of developments at White River Lake, Texas.

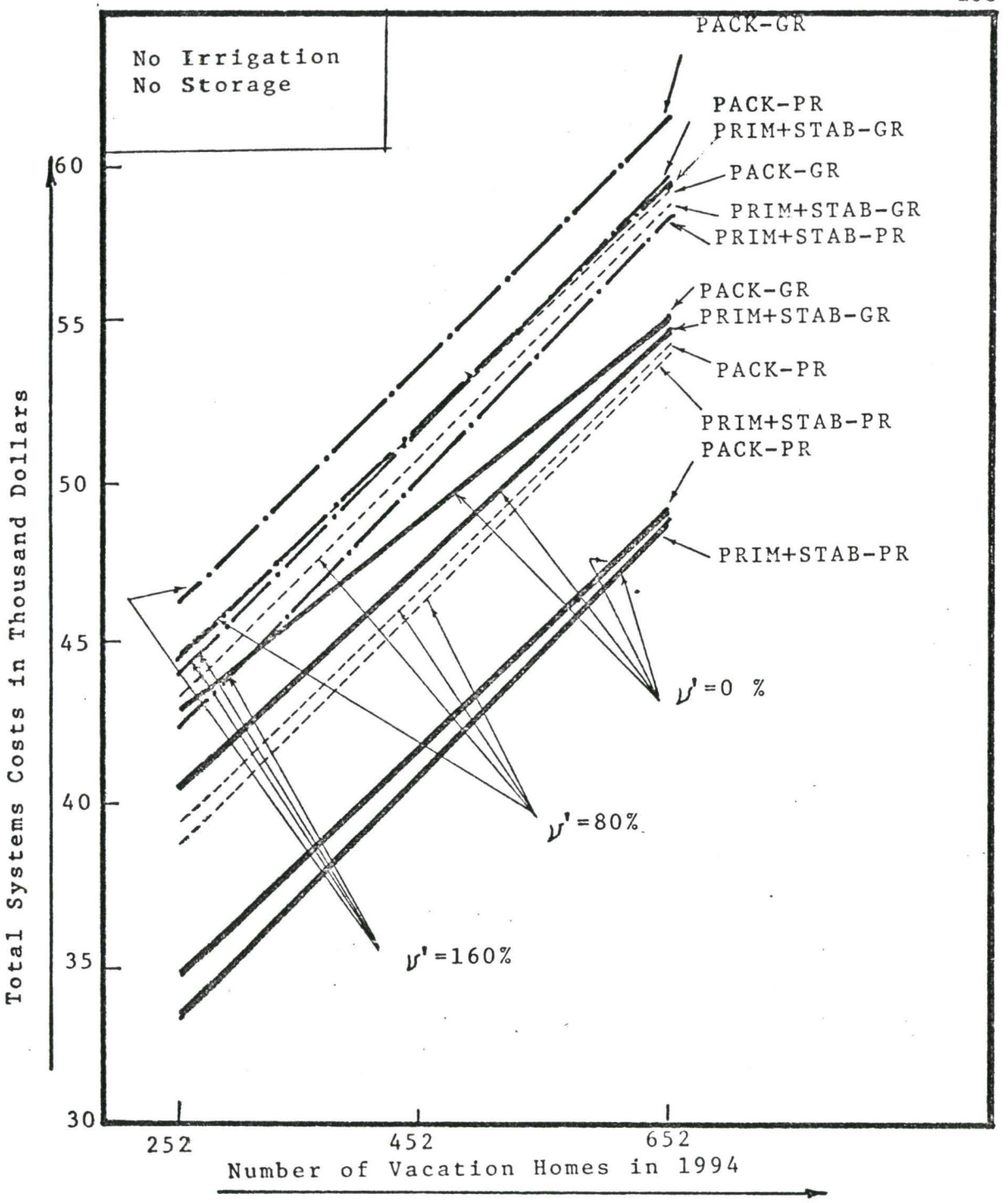

Figure 6.20. Total system costs for alternative collection and treatments methods entailing an irrigation-vegetation system at various assumed rates of developments at White River Lake, Texas.

least cost decision for any rate of development in the case study area. A package treatment plant along with a stabilization pond costs more than a primary treatment plant along with a stabilization pond. However, the latter combination is not technically feasible for submatic irrigation, although this combination is feasible for sprinkler irrigation. Since submatic irrigation is a cheaper method of irrigation than sprinkler irrigation for vegetation strategy 1, a combination of package plant, stabilization pond and submatic irrigation is more economical than the combination of a primary plant-stabilization pond and sprinkler irrigation.

In the case of sprinkler irrigation, stabilization ponds are not required if a high rate trickling filter, standard rate trickling filter, activated sludge or package plant is used whereas any of these secondary treatment plants would also require a stabilization pond for submatic irrigation. The submatic irrigation method needs more treatment of the wastewater compared with sprinkler irrigation which increases the treatment cost. Nevertheless, the economic advantages of submatic irrigation over sprinkler irrigation for vegetation strategy 1 exceed the additional cost needed for a stabilization pond and other filtration costs. It is noted that vegetation strategy 1 involves a large number of trees and hence, a relatively large area of land to be irrigated. As the number of trees increases, submatic irrigation becomes relatively cheaper than sprinkler irrigation. This is clearly indicated if the system costs characteristics for vegetation strategy 1 and for vegetation strategy 2 are compared

in Figures 6.16 and 6.17. Figure 6.17 shows the total system costs for some of the relatively low cost combinations of collection-treatment irrigation alternatives for vegetation strategy 2. Vegetation strategy 2 entails 1000 fewer trees than vegetation strategy 1. This reduction in the number of trees changes the characteristics of total system cost as observed in the case of vegetation strategy 1 in Figure 6.16. In the case of vegetation strategy 2, although a package plant along with a stabilization pond and submatic irrigation is the least cost decision a $\nu' = 0$, the sprinkler irrigation method gradually becomes cheaper as ν' increases. At $\nu' = 80$, the submatic irrigation method no longer provides the least cost decision for vegetation strategy 2. At $\nu' = 80$, the least cost decision is a combination of pressure collection-primary treatment plant-stabilization pond and sprinkler irrigation. It is noted that all least cost decisions for any vegetation strategy, irrespective of whether these involve submatic or sprinkler irrigation, entail the use of pressure collection. This means that the same amount of effluent is available either for sprinkler irrigation or for submatic irrigation for each specific rate of development. But, since irrigation efficiency of sprinkler irrigation is less than that of submatic irrigation, more supplementary water has to be pumped from the lake for sprinkler irrigation at $\nu' = 0$. However, as ν' increases, the amount of effluent available for irrigation increases, which reduces the amount of supplementary water to be pumped from the lake for sprinkler irrigation. Therefore, in the case of vegetation strategy 2,

sprinkler irrigation enters into the least cost decision as ν' increases from 0.0 percent to 80.0 percent.

Vegetation strategy 4 includes the same number of trees as vegetation strategy 2. However, strategy 4 does not entail any irrigation of grass. Submatic irrigation is more expensive than sprinkler irrigation for irrigating lawns. Therefore, as irrigation is not required for vegetation strategy 4, a combination of "pressure collection-package treatment plant-stabilization pond and submatic irrigation" constitutes the least cost decision for any value of ν' (Figure 6.19).

Vegetation strategy 3 has the same number of trees as vegetation strategy 1, but strategy 3 does not include any lawn irrigation. A relatively large number of trees along with no grassed area to be irrigated makes submatic irrigation even more favorable than for vegetation strategy 1. The least cost decision at any ν' and $(NC)_{1994}$ for vegetation strategy 3 is therefore the same as for vegetation strategy 1 (Figure 6.18).

The number of trees involved in vegetation strategies 5 and 6 are the same as for vegetation strategy 3, but these strategies entail different soil uses and planting arrangements. These two strategies were simulated to investigate the interactions of soil and trees. In vegetation strategy 3, 1000 trees of category A are assumed to be planted in latom polar complex soil which is very poor in water-holding capacity. In strategy 5, the 1000 trees planted are assumed to be shifted from latom polar complex soil to Miles fine sandy loam soil

which has the maximum water holding capacity of all the soils considered in this study. As can be seen from Table 6.15, adoption of strategy 5 reduces the entire system cost by about $7,000 at $\nu' = 0$ and $(NC)_{1994} = 252$. Since the soil reservoir provides effluent storage, the high value of water holding capacity of Miles sandy loam provides a relatively large indirect secondary storage at no cost. This reduces pumpage of water from the lake and ultimately reduces the total system cost.

In vegetation strategy 5, the number of trees of category B assumed to be planted on lotam polar complex soil is 500. These same 500 trees are planted on Miles fine sandy loam soil in strategy 6. Table 6.15 shows that the saving in cost due to planting these 500 medium size trees on Miles sandy loam rather than the other soil type in 20 years if $\nu' = 0$ and $(NC)_{1994} = 252$.

Table 6.14 shows a breakdown of total system costs for two combinations of treatment and collection alternatives if the system does not include irrigation. These are "pressure collection-primary treatment plant-stabilization pond" and "pressure collection and package treatment plant." All other combinations of pressure or gravity collection and high rate trickling filter, standard rate trickling filter, or activated sludge treatment plants have higher system costs and are not shown in Table 6.14. Since, in this case, an irrigation system is not connected to the collection and treatment system, a combination of primary plant-stabilization pond and pressure collection constitutes the minimum cost decision for any rate of development

TABLE 6.14

TOTAL SYSTEM COSTS AND ITS BREAKDOWN FOR ALTERNATIVE TREATMENT PLANTS AND COLLECTION SYSTEMS IN CASE OF STRAIGHT DISPOSAL OF THE TREATED EFFLUENT WITHOUT USING IT FOR IRRIGATION AT VARIOUS ASSUMED RATES OF DEVELOPMENTS AT WHITE RIVER LAKE, TEXAS

Treatment Plant		No. of Vacation Homes in 1994	F(I) : Fixed Cost for Irrigation System (dollars)	F(C) : Fixed Cost for Collection System		F(T):Fixed Cost for Treatment		T(F):Total Fixed Cost		T(O):Total Operation and Maintenance Cost		T(S):Total System Cost	
				Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure	Gravity	Pressure
		252		272915	214382	85533	67160	358448	281542	47668	51233	406116	332775
Primary	0	452	0	330215	289662	93208	70220	423423	359882	54138	51989	477553	411871
+		652		387585	364941	a	74230	a	439171	a	52501	a	491672
Stabilization		252		272915	228507	105533	a	378448	a	55587	a	434035	a
Pond	80	452	0	330215	303789	121868	91940	452083	395729	58562	65378	510645	461107
		652		387585	379070	137820	95510	526405	474580	61536	65633	586941	540213
	160	252		272915	242636	109978	101285	382893	343921	63129	80754	446022	424675
		452	0	330215	317917	122356	104414	452571	422331	65923	81526	518494	503857
		652		387585	393198	138308	109878	525893	503076	68771	82321	594664	585396
		252		272915	214382	87807	68714	360722	283095	64276	64024	424998	347120
	0	452	0	330215	289662	93088	71645	423303	361307	67150	64809	490453	426116
Package		652		387585	364941	a	74517	a	439458	a	65212	a	504670
Plant		252		272915	228507	103807	a	376722	a	68779	a	445501	a
	80	452	0	330215	303789	117688	89304	447903	393093	70874	77747	519777	470840
		652		387585	379070	130867	91866	518452	470936	73800	78686	592252	549622
		252		272915	242636	119686	102835	392601	345471	73214	93302	465815	438773
	160	452	0	330215	317917	140647	105217	470862	423134	74598	93897	545460	517031
		652		387585	393198	153792	107569	541377	500767	75947	94615	617324	595382

[a]Not Simulated

TABLE 6.15

TOTAL SYSTEM COSTS, COSTS PER VACATION HOMES AND ADDITIONAL COSTS FOR INCLUDING THE IRRIGATION SYSTEM AT VARIOUS RATES OF DEVELOPMENT AT WHITE RIVER LAKE, TEXAS CORRESPONDING TO OPTIMUM DECISION ON TREATMENT-COLLECTION AND IRRIGATION ALTERNATIVES

λ' %	Vegetation Strategy	Number of Vacation Homes in 1994	Optimum Decision on Collection-Treatment and Irrigation Alternatives	Total System Cost	Cost per Vacation Homes	Increase in Total System Cost due to Incorporating Irrigation System
0.0	No Irrigation	252	PRIM+STAB : PR	332775	1320	0
		452	PRIM+STAB : PR	411871	911	0
		652	PRIM+STAB : PR	491672	754	0
	1	252	PACK+STAB : PR-SUB	535997	2126	203222
		452	PACK+STAB : PR-SUB	615229	1361	203358
		652	PACK+STAB : PR-SUB	694701	1065	203029
	2	252	PACK+STAB : PR-SUB	509601	2022	176588
		452	PACK+STAB : PR-SUB	588459	1301	176588
		652	PACK+STAB : PR-SUB	667316	1023	175644
	3	252	PACK+STAB : PR-SUB	486020	1928	153745
		452	PACK+STAB : PR-SUB	566063	1252	154192
		652	PACK+STAB : PR-SUB	646106	990	154434
	4	252	PACK+STAB : PR-SUB	458758	1820	125983
		452	PACK+STAB : PR-SUB	538813	1192	126942
		652	PRIM+STAB : SPR-PR	607335	931	115663
	5	252	PACK+STAB : PR-SUB	478825	1900	146050
		452	PACK+STAB : PR-SUB	558742	1236	146871
		652	PACK+STAB : PR-SUB	639004	980	147332
	6	252	PACK+STAB : PR-SUB	478680	1899	145905
		452	PACK+STAB : PR-SUB	558610	1235	146739
		652	PACK+STAB : PR-SUB	638915	979	139243

TABLE 6.15--Continued

σ' %	Vegetation Strategy	Number of Vacation Homes in 1994	Optimum Decision on Collection -Treatment and Irrigation Alternatives	Total System Cost	Cost per Vacation Homes	Increase in Total System Cost due to Incorporating Irrigation System
80	No Irrigation	252	PRIM+STAB : PR	382011	1515	0
		452	PRIM+STAB : PR	461107	1020	0
		652	PRIM+STAB : PR	540213	828	0
	1	252	PACK+STAB : PR-SUB	588078	2333	206067
		452	PACK+STAB : PR-SUB	666997	1475	205890
		652	PACK+STAB : PR-SUB	745916	1144	205703
	2	252	PRIM+STAB : PR-SPR	562875	2233	180864
		452	PRIM+STAB : PR-SPR	639758	1415	178651
		652	PRIM+STAB : PR-SPR	716641	1099	176428
	3	252	PACK+STAB : PR-SUB	540764	2145	158753
		452	PACK+STAB : PR-SUB	620329	1372	159222
		652	PACK+STAB : PR-SUB	699894	1073	159681
	4	252	PACK+STAB : PR-SUB	493230	1957	111219
		452	PACK+STAB : PR-SUB	586650	1297	125543
		652	PACK+STAB : PR-SUB	680070	1043	139857
	5	252	PACK+STAB : PR-SUB	533732	2117	151721
		452	PACK+STAB : PR-SUB	613408	1357	152301
		652	PACK+STAB : PR-SUB	693059	1062	152846
	6	252	PACK+STAB : PR-SUB	533650	2117	151639
		452	PACK+STAB : PR-SUB	613333	1356	152226
		652	PACK+STAB : PR-SUB	680116	1062	139903

TABLE 6.15--Continued

ν' %	Vegetation Strategy	Number of Vacation Homes in 1994	Optimum Decision on Collection-Treatment and Irrigation Alternatives	Total System Costs	Cost per Vacation Home	Increase in Total System Cost for incorporating Irrigation System
160	No Irrigation	252	PRIM+STAB : PR	424675	1685	0
		452	PRIM+STAB : PR	503857	1114	0
		652	PRIM+STAB : PR	585396	897	0
	1	252	PACK+STAB : PR-SUB	640067	2539	215392
		452	PACK+STAB : PR-SUB	719083	1590	215226
		652	PACK+STAB : PR-SUB	797982	1223	212586
	2	252	PRIM+STAB : PR-SPR	597115	2369	172440
		452	PRIM+STAB : PR-SPR	675776	1495	171919
		652	PRIM+STAB : PR-SPR	754437	1157	169041
	3	252	PACK+STAB : PR-SUB	592663	2351	167988
		452	PACK+STAB : PR-SUB	671824	1486	167967
		652	PACK+STAB : PR-SUB	750935	1151	165539
	4	252	PACK+STAB : PR-SUB	546048	2166	121373
		452	PACK+STAB : PR-SUB	624960	1382	121103
		652	PACK+STAB : PR-SUB	703858	1079	118462
	5	252	PACK+STAB : PR-SUB	599588	2379	174913
		452	PACK+STAB : PR-SUB	678537	1501	174686
		652	PACK+STAB : PR-SUB	756849	1160	171453
	6	252	PACK+STAB : PR-SUB	599667	2379	174992
		452	PACK+STAB : PR-SUB	678599	1501	174742
		652	PACK+STAB : PR-SUB	756888	1160	171492

in vacation homes at the case study area. It is noted that the combination of a package treatment plant and pressure collection has a system cost very similar to that of a "primary-stabilization pond and pressure collection" system.

System Costs per Vacation Home

The least cost decisions at various assumed rates of developments at the case study area and total system costs corresponding to different vegetation strategies are identified in Table 6.15. If the central sewage treatment plant is not integrated with an irrigation vegetation system, the entire system cost may be attributed to the vacation homes. On this basis, the cost share of installing the central treatment plant per vacation home is estimated at \$1320, \$911, and \$754 for 252, 252, and 652 number vacation homes, respectively. These cost figures are shown by the line "\$/home, if not irrigated, $\nu' = 0$" in Figure 6.21. In evaluating the cost characteristics, the entire system cost is assumed to be assigned to the vacation homes, even if the system entails an irrigation vegetation strategy. System costs per vacation home are plotted against $(NC)_{1994}$ in Figure 6.20 for various vegetation strategies.

Present Worth of Revenues Received

Table 6.16 shows the present worth of revenues received at various assumed rates of developments. These have been plotted against $(NC)_{1994}$ and against ν' in Figure 6.22. The present worth of revenues received from leasing the lots for vacation homes and from selling

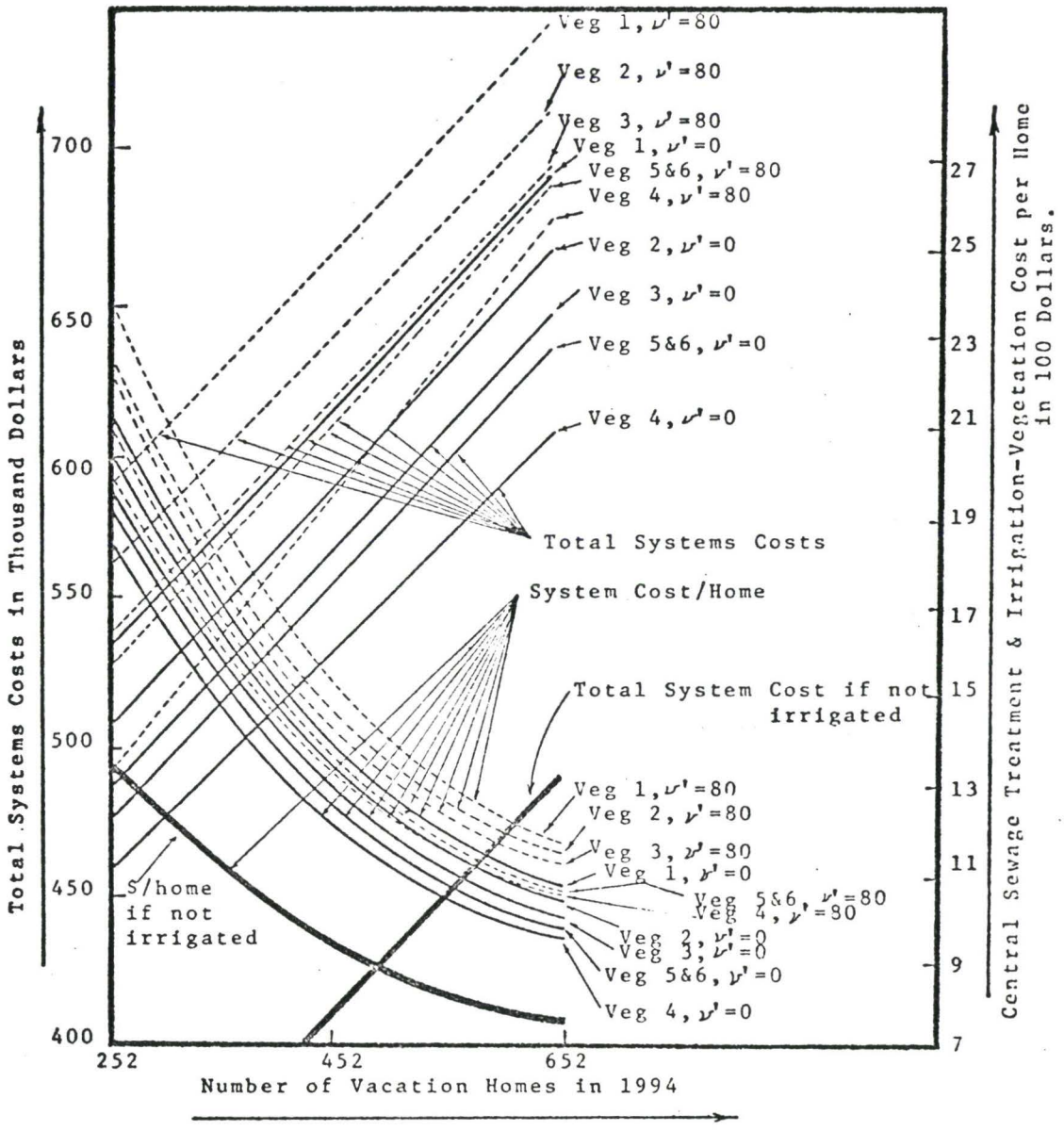

Figure 6.21. Total system costs and system costs per vacation home associated with the least cost decisions corresponding to different vegetation strategies at various assumed rates of developments at White River Lake, Texas.

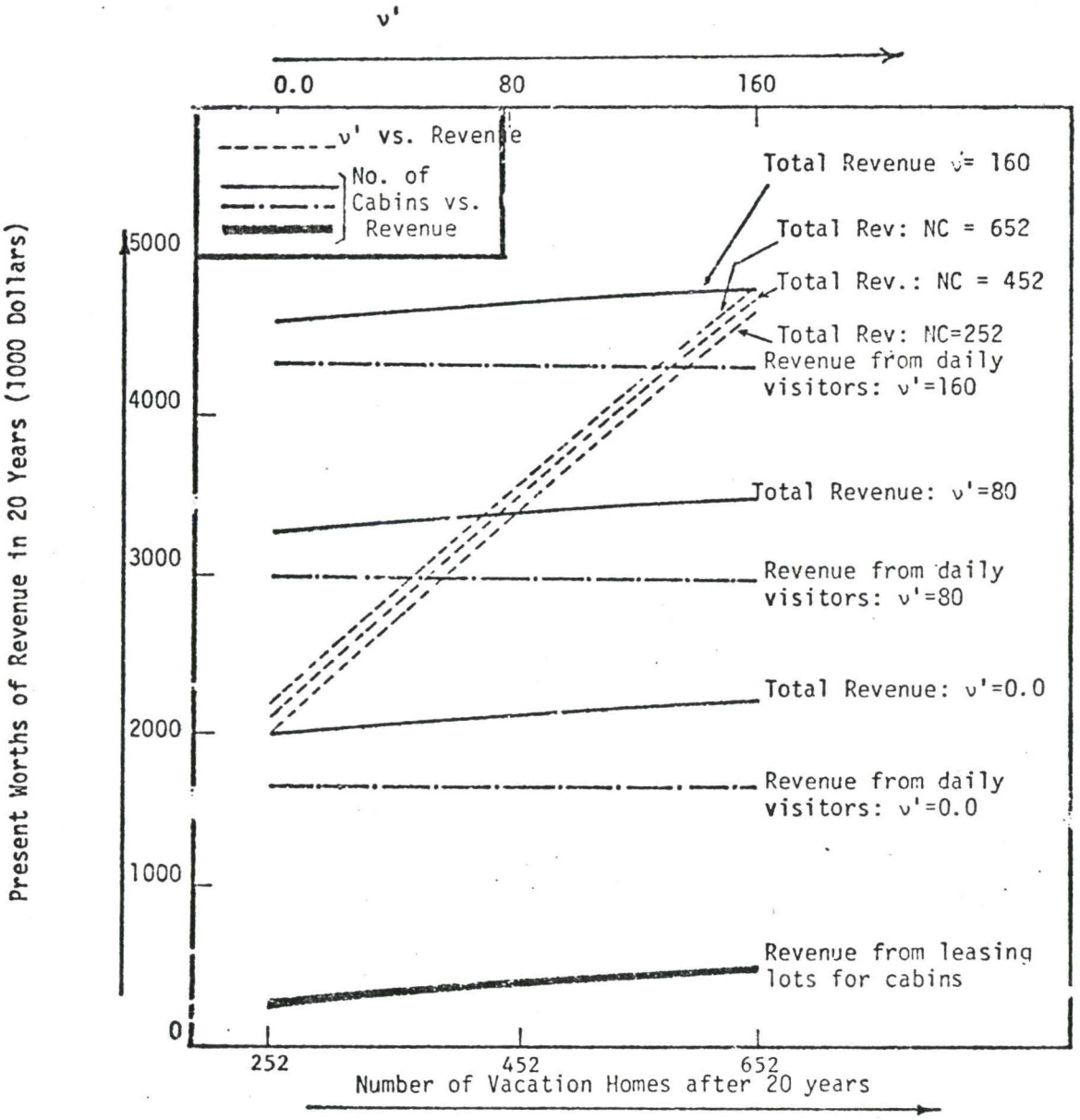

Figure 6.22. Present worths of revenues received from leasing lots for vacation homes and daily recreation permit sales in 20 years.[a]

[a]All cost figures are subject to Assumption Set A.

daily recreation permits in the period 1975-1994 is about 1.95 million dollars if the existing facilities are not expanded (Table 6.16 and Figure 6.22). Out of this $1.95 million, $1.65 million is obtained from daily permits and $0.289 million from leasing lots for vacation homes. If a central treatment plant is adapted, the number of vacation homes may be increased without causing any potential danger of municipal water pollution. If the central treatment plant does not entail an irrigation system, there is assumed to be no change in the historic rate of increase of visitors with daily permits. Therefore, the option of adopting a central treatment plant without using the effluent for irrigation does not provide any additional revenues from daily visitors. However, Table 6.16 shows that additional revenues received from increased leasing of lots for vacation homes are 98.7 and 197.5 thousand dollars, respectively.

Table 6.16 and Figure 6.22 also show the effects of increasing ν' by increasing the attractiveness of daily recreation facilities. For example, if the improved system can attract 80 percent more daily visitors than that predicted from the past trend in visitation, an additional 1.328 million dollars would be received from increased sales of daily recreation permits (Table 6.16).

Costs and Benefits

The simulation model as applied to the case study area provided various cost information associated with different treatment-collection and irrigation alternatives. The least cost decisions at

TABLE 6.16

PRESENT WORTHS OF REVENUES RECEIVED FROM LEASING LOTS FOR VACATION HOMES AND FROM DAILY RECREATIONAL PERMIT SALES AT VARIOUS ASSUMED RATES OF DEVELOPMENTS FOR 1975-1994 AT WHITE RIVER LAKE, TEXAS

Increased Growth Rate In Daily Visitation Attributed to Improvements of the Campgrounds. (i')	Number of Lots Leased in 20 Years. (NC) 1994 ($)	Present Worths of Revenues from Leasing the Lots in 20 Years. ($)	Present Worths of Revenues Received from Daily Visitors in 20 Years. ($)	Present Worth of Total Revenues Received in 20 Years. ($)	Present Worth of Revenue Due to Irrigation in 20 Years. ($)	Present Worth of Revenue Due to Further Vacation Homes. ($)
0%	252	289149.		1952661.		0
	452	387888.	1663512.	2051400.	0	98739.
	652	486633.		2150145.		197484.
80%	252	289149.		3280556.		0
	452	387888.	2991407.	3379295.	1327895.	98739.
	652	486633.		3478040.		197484.
160%	252	289149.		4599547.		0
	452	387888.	4310398.	4698286.	2646886.	98739.
	652	486633.		4797031.		197484.

various assumed rates of developments have been identified. However, corresponding benefits from any of these decisions cannot be explicitly defined. There are two major difficulties in drawing any definite conclusions regarding the benefits of adopting a central treatment plant with or without the addition of an irrigation-vegetation system. The first one arises from the very definition of "benefit" itself. Before defining the "benefits" from adopting a central treatment plant and subsequent irrigation of shade trees, a vital question needs to be answered. The question is: "Are the existing septic tank treatment facilities adequate to maintain the quality of the municipal supply water over a long-range period if there is no further development at the site?" An appropriate answer to this question would require extensive field investigations on septic tank performance, sewage flow characteristics, rainfall patterns, volume of water in the lake reservoir, etc. This study did not evaluate this important aspect of the system and hence, this study is unable to provide any definite conclusion on the adequacy of existing septic tank methods.

Although no case of septic tank pollution in the lake has been reported at the present stage of development, there is no assurance that this problem would not arise in the future, even if the number of vacation homes is not increased. In Grandview Lake, Indianapolis (68) inefficient septic tank systems have caused serious polution of the lake even with 120 vacation homes. As indicated in Chapter 1, there are many reported cases of septic tank pollution in various recreational areas of the U.S. The concept of "benefit" changes if

it is assumed that a central treatment plant must be provided for the study area even if the number of vacation homes is not increased in the future. In a later part of this section, costs and benefits of adopting a central treatment plant are analyzed from two different points of view.

A second difficulty arises from the inability of the model to quantify benefits associated with the various vegetation strategies directly. It was not possible to assign a definite value for ν' in the model for each vegetation strategy. However, there are other approaches available for valuing ν'. One approach is to identify the minimum values of ν' that would need to be generated by the system to break even on irrigation costs. A second approach to this problem is discussed in the last section of this chapter where the shade trees are assigned specified dollar values per square inch of trunk cross-section (26). The benefits of adopting vegetation strategies are calculated using these values.

Case 1: Costs and Benefits with a Required Central Treatment Plant

According to this assumption, a central treatment plant would be required at the case study area, irrespective of possible benefits from associated expansion, if any, in the number of vacation homes at the site. In this situation, the total cost of sewage collection and central treatment systems would be higher than the present worth of revenues received from leasing lots for 252 vacation homes at the current average annual rate of $100 per lot (Figure 6.23). As shown

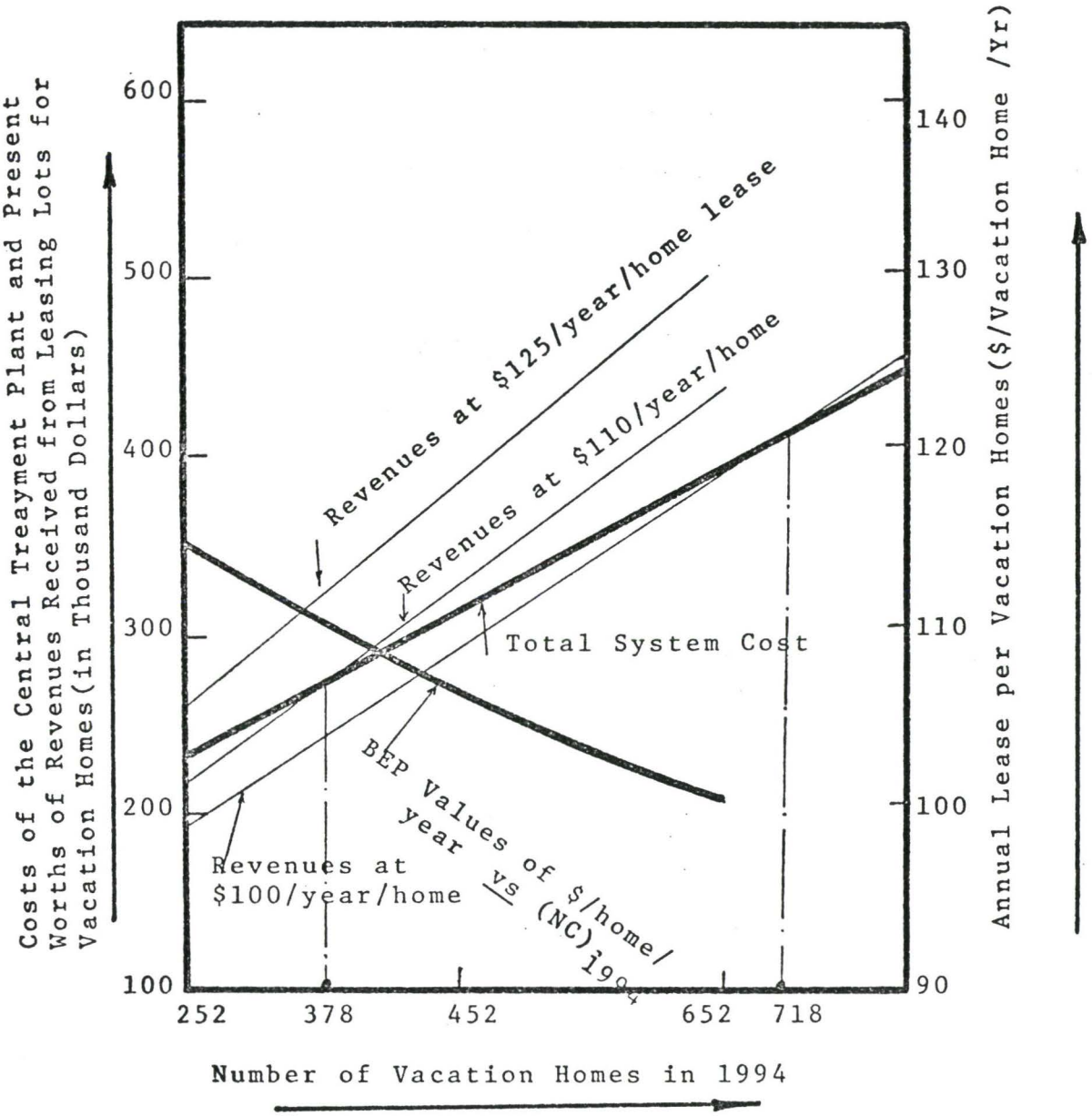

Figure 6.23. Costs of central sewage treatment plant, present worths of revenues received and breakeven values of annual lease per lot of vacation homes as various assumed number of vacation homes at White River Lake, Texas.

in Figure 6.23, the number of vacation homes needed at the site to break even on costs of the collection and central sewage treatment system is 718. One alternative to increasing the number of vacation homes at the site in order to bear the high cost of a central treatment system is to increase the leasing rates for the lots per year. Figure 6.23 shows the present worth of revenues received over a 20-year planning period at various assumed lease rates per year for vacation home lots. It is observed in Figure 6.23 that if the annual lease rate per lot for vacation home is \$110, then the number of vacation homes needed to break even on the central treatment plant cost is 378. Other breakeven levels for vacation home lots are plotted against $(NC)_{1994}$ in Figure 6.23. These are shown by the line "BEP values of \$/home/year vs $(NC)_{1994}$" in the graph. It may be observed from this line that if there is no further increase in the number of vacation homes at the site, then the annual lease rate per lot for vacation homes should have to be at least \$125 in order to break even on the cost of a central sewage treatment system. On the other hand, if the number of vacation homes is increased to 452, the breakeven lease value per lot is only \$106.

If a central sewage treatment plant is required for the case study area, irrespective of the number of the vacation homes, then the decision problem only concerns the costs of the irrigation-vegetation system along with the cost of any additional effluent treatment required for irrigation use. The last column in Table 6.15 shows the additional costs for incorporating an irrigation system

with alternative vegetation strategies. Corresponding benefits associated with adopting vegetations strategies may be related to the additional revenue received from daily recreation permit sales. The benefits of the irrigation system, so defined are plotted along corresponding irrigation-vegetation costs against ν' in order to identify the minimum values of ν' which would need to be generated by the different vegetation strategies to break even on irrigation costs (Figure 6.24). Increases in the number of vacation homes provide more effluent for irrigation. However, the additional effluent increases the cost of treatment required for irrigation. In view of these slight additional treatment costs, the variation of the irrigation-vegetation systems cost with increasing numbers of vacation homes is relatively small. For example, for any specific ν' and vegetation strategy, the cost of irrigation and vegetation program does not fluctuate by more than $1000 if the number of vacation homes is increased from 252 to 652 (Table 6.15). Therefore, the cost curves in Figure 6.24 are independent of $(NC)_{1994}$. The last three columns of Table 6.17 show the breakeven values of ν' for irrigation and vegetation strategies corresponding to different vegetation strategies.

Case 2: Costs and Benefits with an Optional Central Treatment Plant

In this situation, the major purpose of the central sewage treatment plant and irrigation system is to supply effluent to the irrigation system. Additional revenues received from increases in number of vacation homes, if any, are a secondary benefit. Hence, the

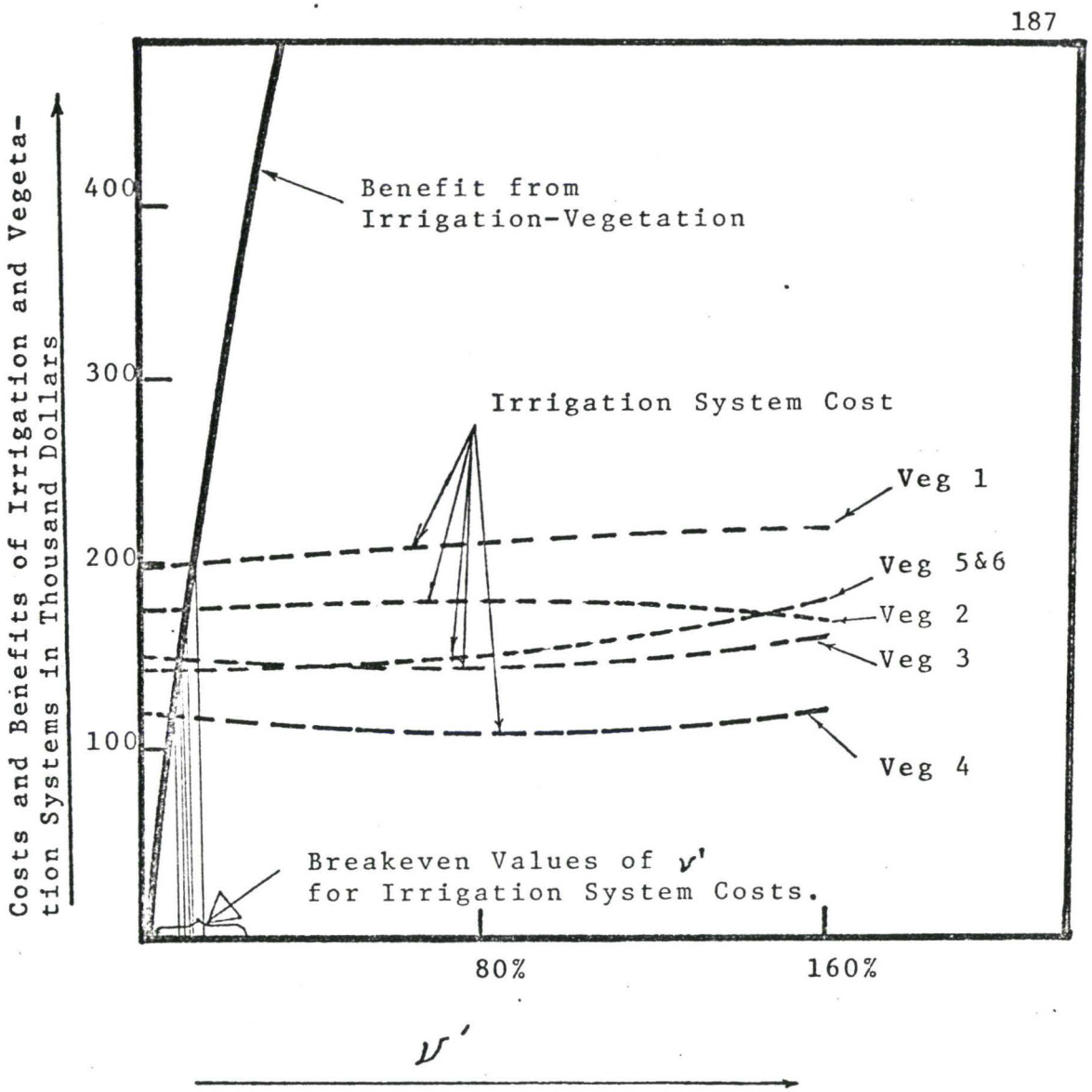

Figure 6.24. Costs and benefits from various irrigation and vegetation strategies at different assumed values of v' at White River Lake, Texas.

TABLE 6.17

BREAKEVEN VALUES OF $\int'$ FOR TOTAL SYSTEM COSTS AND IRRIGATION SYSTEM COSTS FOR VARIOUS VEGETATION STRATEGIES AT WHITE RIVER LAKE, TEXAS

Vegetation Strategy	Breakeven Values of $\int'$ for Total System Costs			Breakeven Values of ν' for Irrigation System Costs		
	Number of Vacation Homes in 1994			Number of Vacation Homes in 1994		
	252	452	652	252	452	652
1	29.33	28.26	26.13	15.00	15.00	15.00
2	26.66	25.86	25.06	14.00	14.00	14.00
3	26.13	24.54	22.93	12.50	12.50	12.50
4	23.30	23.40	21.86	11.00	11.00	11.00
5	25.06	24.00	22.40	10.00	10.00	10.00
6	25.06	24.00	22.40	10.00	10.00	10.00

cost of the central treatment plants and irrigation have to be justified on the basis of revenues generated from additional daily visitors and from revenues received from additional vacation homes. Thus, the "benefit" of the systems in this case is defined as "the revenue received from additional daily permits sales plus the revenues received from additional vacation homes, if any." According to this definition, if $(NC)_{1994}$ is 252 and ν' is zero, then no benefit is obtained from changing the system. The costs and benefits of the system so defined, are plotted against ν' for vegetation strategy 1 in Figure 6.25. This shows the breakeven values of ν' for vegetation strategy 1 for various assumed numbers of vacation homes in 1994. If the central treatment plant is adopted only to provide the effluent for irrigation, then as shown by the lines "Total Benefit" and "Total System Cost" in Figure 6.25, the minimum value of ν' needed to be generated by vegetation strategy 1 is 29.33. Other break even values for ν' corresponding to different vegetation strategies are shown in the first three columns of Table 6.3. If the number of vacation homes is increased, the revenues received from the additional homes increases. Hence, the values of ν' to break even on cost decreases as $(NC)_{1994}$ increases. The characteristics of breakeven values for ν' with various vegetation strategies are illustrated in Figure 6.26.

An Alternative Approach to Evaluate Benefits of the Irrigation-Vegetation System

Since the direct benefits of various vegetation strategies could not be exactly quantified, previous sections of this chapter

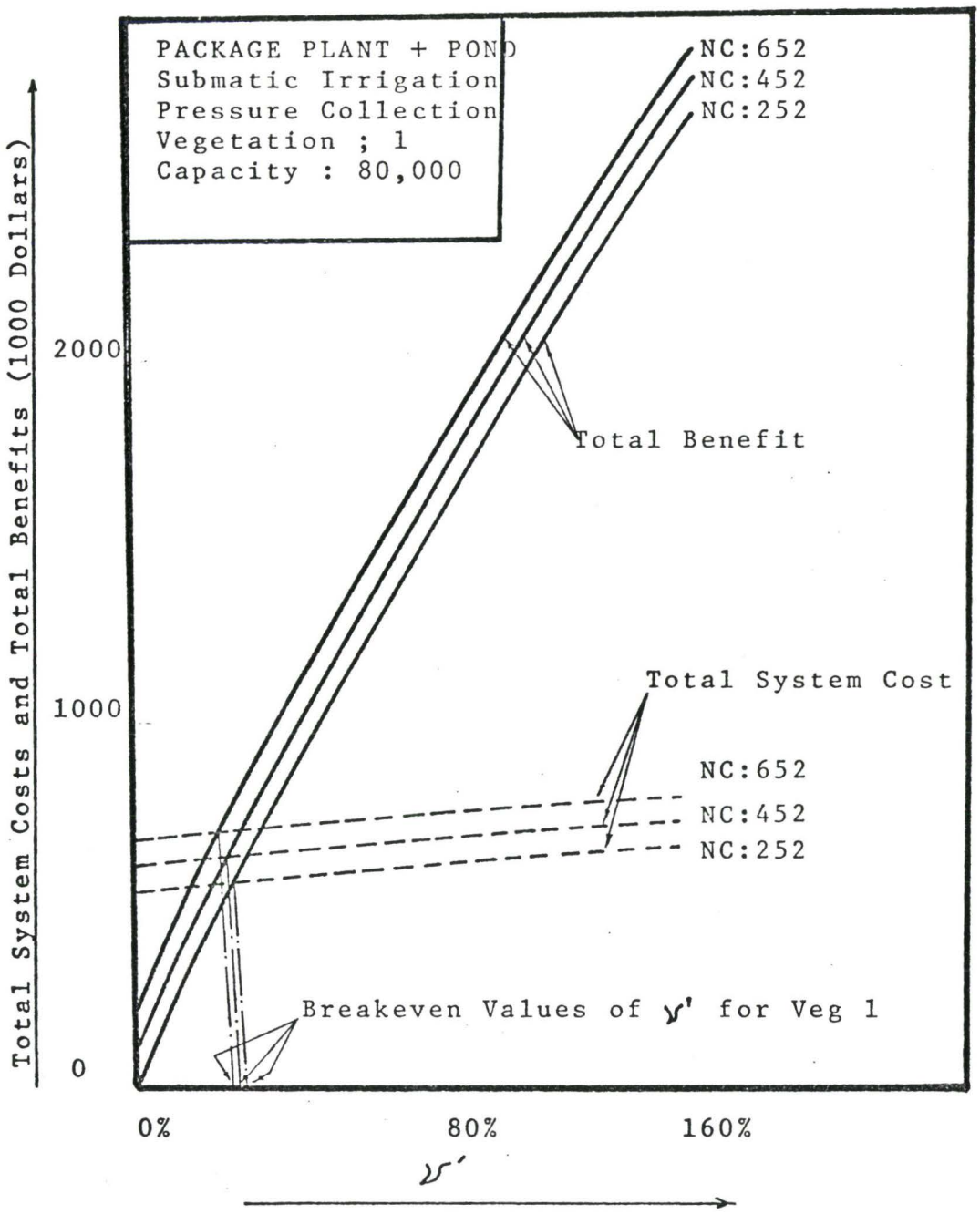

Figure 6.25. ɣ ' vs total systems costs and present worths of increased revenue (benefits) in 20 years.

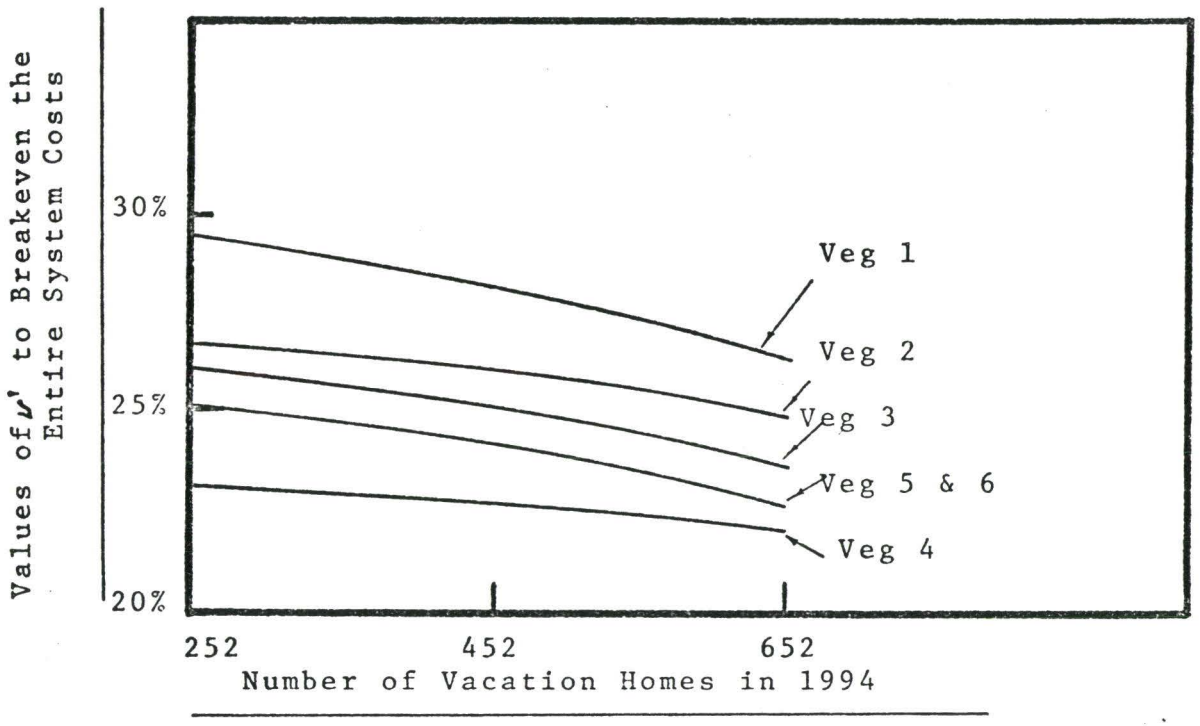

Figure 6.26. Values of ν' required to be generated by various vegetation strategies to breakeven the entire system costs at different assumed numbers of vacation homes at White River Lake, Texas.

attempted to identify how much the rate of growth in daily visitation would have to be increased by each vegetation strategy to justify adopting these strategies. The applied simulation model provided a detailed cost analysis and information on the interrelationships among the system variables but did not identify an optimum vegetation strategy. The following is an alternative method of valuing vegetation strategies. The Executive Committee of the International Shade Tree Conference (26) adopted $10.00 per square inch of trunk cross-section as the average value of shade trees in the U.S. Utilizing these guidelines, the vegetation strategies for the case study were calculated at two different assumed values per square inch of trunk cross-section. These are $5.00 and $10.00 per square inch, respectively, representing wholesale and retail prices for the trees. No comporable data were obtained to evaluate the lawns. Hence, only vegetation strategies 4 and 6, which do not include any irrigated grass, are considered. The "benefits" of irrigation-vegetation systems are defined as the "present worth of the total dollar values of shade trees in 1994." Table 6.18 shows the costs and benefits of vegetation strategies 4 and 6 using values for shade trees of $5.00 and $10.00 per square inch of trunk cross-section. These costs and benefits are plotted in Figure 6.27. Figure 6.27 also shows the breakeven values for tree production in terms of "square inches of trunk cross-section" to be grown in 20 years for the case study area. These values have been converted to "number of trees of category A" in order to quantify the number of shade trees to be

TABLE 6.18

COSTS AND BENEFITS FOR IRRIGATION AND VEGETATION AT WHITE RIVER LAKE, TEXAS AT VARIOUS ASSUMED VALUES OF DOLLARS PER SQUARE INCH OF TRUNK CROSS-SECTION OF SHADE TREES

Square Inches of Trunk Cross-Section of Trees Grown	Number of Vacation Homes in 1994	Costs for Irrigation and Vegetation ($) c	Total Cost for the entire Collection-Treatment-Irrigation System ($) d	Benefit from Shade Trees Grown (in Dollars) e		Benefit from Additional Vacation Homes. ($) f	Total Benefit	
				@ $5 per sq. inch	$10 per sq.inch		$5 per sq.inch	$10 per sq.inch
133,533 [a]	252	125983	458758	208181	416362	0	208181	416362
	452	126942	538813			98739	306920	515101
	652	115663	607335			197484	405665	613845
228565 [b]	252	145905	478680	356338	712676	0	356238	712676
	452	146739	558610			98739	455077	811415
	652	139243	638915			197484	553822	910160

[a] Evaluated from Vegetation Strategy 4.
[b] Evaluated from Vegetation Strategy 6.
[c] Taken from the last columns of Table 6.15 for Vegetation Strategies 4 and 6.
[d] Taken from column 5 of Table 6.15 for '=0 and for Vegetation Strategies 4 and 6.
[e] Present worths of the values of shade trees in]994 at 6 percent interest rate.
[f] Taken from the last column of Table 6.16.

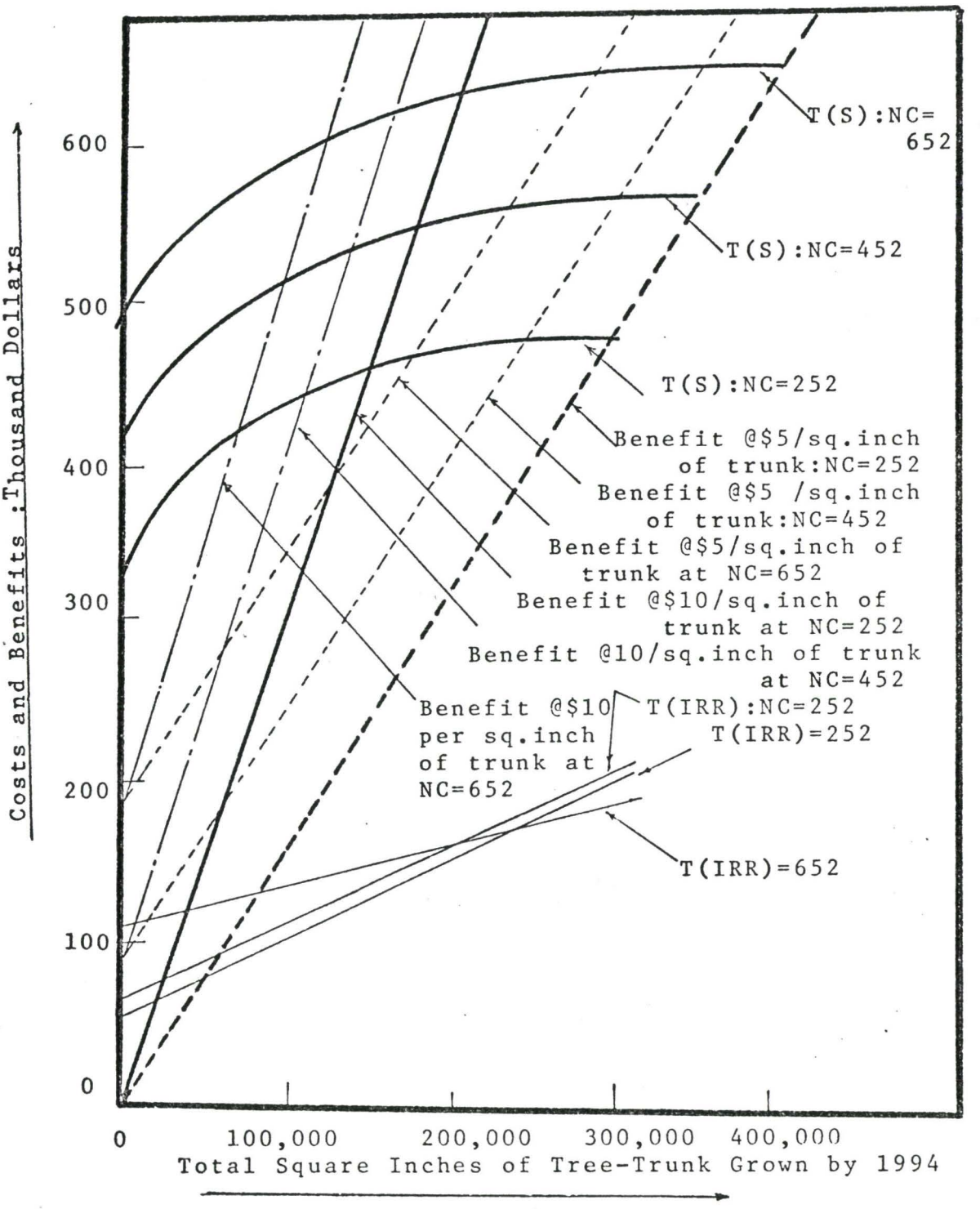

Figure 6.27. Costs and benefits of central sewage treatment plants and irrigation-vegetation systems at White River Lake, Texas.

grown to justify the irrigation and vegetation costs as well as the number of trees needed to justify the entire system costs. These values are tabulated in Table 6.19.

TABLE 6.19

BREAKEVEN VALUES OF TOTAL SQUARE INCHES OF TREE TRUNK GROWN AT WHITE RIVER LAKE, TEXAS[a]

Number of of Vacation Homes in 1994	Values of Square Inches of Tree Trunk Grown in 20 Years in order to Breakeven the Cost of Irrigation and Vegetation (Sq. Inches)		Square Inches of Tree Tree Trunk Grown in 20 Years in order to to Breakeven the Total Collection-Treatment and Irrigation Cost (Sq. Inches)		Approximate Number of Shade Trees of Catagory A Needed to to be Crown to Breakeven the rrigation-Vegetation Costs only.[b]		Approximate Number of Shade Trees of Catagory A needed to Breakeven the Entire System Costs [b]	
	@$5/Sq.Inch	@$10/Sq.Inch	@$5 per Sq.Inch	@$10 per Sq. Inch	@$5 per Sq. Inch	@$10per Sq.Inch	@$5 per Sq. Inch	$10per Sq. Inch
252	50,000	20,000	310,000	150,000	526	210	3262	1579
452	61,000	28,000	300,000	130,000	641	295	3156	1368
652	80,000	40,000	295,000	122,000	841	420	3104	1284

[a] In this case, daily visitation in the campground, trailor parking areas, boating or fishing facilities are not assumed to be increased at an acclelerated rate due to the growth of shade trees.

[b] The effects of growth characteristics of various trees have been disregarded.

CHAPTER 7

CONCLUSION

The purpose of this chapter is to summarize the methodology and findings of the study. The chapter is divided into four sections: methodology, recommendations as applicable to the case study area, limitations of the study, and suggestions for further research.

Methodology

This study illustrated the use of a system model to conjunctively evaluate alternative methods of domestic sewage collection, treatment, and disposal via irrigation for a second home development project. The model considers the increases in effluent loading rates associated with additional developments of the project over time and is designed to select the least cost combinations of collection, treatment and disposal facilities for specified environmental restrictions. The model developed in this study has been applied to White River Lake, Texas as a case study. The collection, treatment and irrigation alternatives considered while applying the model are: pressure or gravity collection, primary treatment and/or any one of all secondary treatment or their combinations along with submatic drip irrigation or sprinkler irrigation of various types of shade trees. The specific methodology employed in this study is to use a computerized dynamic systems simulation model to simulate the visitation, sewage flow,

rain and pan evaporation and irrigation requirements of shade trees and lawns on daily basis for a period of 20 years (1975-1994) for various combinations of alternative decision variables at different assumed rates of developments. The simulator accumulates all relavant statistics regarding visitation, sewage volume, irrigation application, etc. and presents the final cost figures on the basis of present worths of the costs involved in various distinct components of system. The simulated cost figures corresponding to alternative combinations of decision variables are then analyzed to identify the least cost decision. In addition to this, the model identifies the minimum rate of developments or minimum number of vacation homes and shade trees needed at the recreational area in order to break even the total cost of collection, treatment and disposal system in the next twenty years.

Recommendation as Applied to White River Lake, Texas

Primary use of White River Lake is municipal water supply. However, there is a shortage of water-based recreational areas in West Texas, and this lake has high potential for recreational development because of its close proximity to a growing metropolitan area. The water district has leased 252 home lots for second home development along the lake shore that are serviced by individual septic tank installations. The soil represented in septic tank drainage fields are relatively shallow with low permeability. Although no cases of septic tank pollution in the lake have been reported, there appears to be a potential problem in continuing development of second homes

without adopting a common wastewater collection and treatment system. Failure of septic tank treatment system to maintain the quality of lake water is not uncommon. In Grandview Lake, Columbus, Indiana the individual septic tanks of 120 shoreline vacation homes had to be replaced by central sewage treatment plant in order to save the lake water from serious pollution. Similarly, in Phoenixville, Pennsylvania, the septic tanks serving several existing houses were not performing well. With the aid of an EPA demonstration grant, grinder pump units were installed for collecting the domestic sewage to a central treatment plant. For these reasons, this study recommends a central sewage treatment plant at the case study area. Adoption of a central sewage treatment would not only save the lakewater from any possible serious pollution, it would allow the water district to expand the existing recreational facilities.

This study illustrated the superiority of a pressure collection method over a conventional gravity collection method at White River Lake, as long as the number of vacation homes at the site do not exceed 582 homes in 1994. However, although the installation cost of a gravity collection system becomes less than that of the pressure collection system at certain level of developments, the combined costs of collection and treatment is always lower in case of pressure collection at any projected rate of developments at White River Lake by 1994. This is due to the fact that a treatment plant connected to a pressure collection system does not need to be overdesigned in order to keep the allowance for possible infiltration. For this reason,

this study suggests a pressure collection method at the case study area.

The selection of a treatment alternative largely depends on the associated irrigation and vegetation plan. If the central treatment plant is not connected to an irrigation system, then the cost of installing and operating the central sewage treatment plant per vacation home has been found to be $1320, $911 and $754 at 252, 452 and 652 number of vacation homes in 1994, respectively (Figure 6.21). In this situation, a combination of pressure collection, primary treatment plant and stabilization pond is the least cost decision. However, the number of vacation homes needed to break even the central sewage treatment system is about 718 by 1994 (Figure 6.23).

The area surrounding White River Lake is currently barren except for scattered mesquite bushes. The campers are usually required to use some form of canopy to obtain shade. This is why this study suggests to entail an irrigation-vegetation system at the case study area. Though the increase of attractiveness of the site due to some specific vegetation plan could not be quantified in this study, a reasonable dollar value has been assigned the shade trees to be developed. The Executive Committee of the International Shade Tree Conference (26) adopted $10.00 per square inch of trunk cross section as the average value of shade trees in the U.S. This study illustrated that about 1400 large shade trees are needed to be grown in order to break even the entire collection-treatment-irrigation and vegetation system cost (Table 6.19) if the shade trees are evaluated

at $10.00 per square inch of trunk cross section. If the vegetation plan does not include any grassed area, the least cost decision usually constitutes a "package treatment plant-stabilization pond-pressure collection and submatic irrigation." Other relevant interacting relationships among treatment alternatives and vegetation plans have been elaborately discussed in Chapter 6.

Limitations of the Study

This study illustrates a systems approach for analyzing a sewage collection, treatment and disposal of effluents via irrigation systems in a recreational area. The validity of the study, like any other systems analysis model is limited by various assumptions. Some of the major limitations of this study are listed below:

i) The study does not consider any technological advancement in sewage collection, treatment and in irrigation practice.

ii) The model, though updating the cost estimating techniques of the past researchers by using various cost indexes, does not consider any variation in different cost figures within the next 20 years.

iii) The model extrapolates the past trend in visitation in order to estimate the visitation in the next 20 years. This assumption may not be valid because the socioeconomic structures and populations of the nearby cities may not increase at the same rate as these did in past years.

iv) In the case of White River Lake, Texas, the study assumes the value of lakewater as 10¢ per 1000 gallons. The value of water in Texas in the next 20 years is difficult to quantify. The groundwater table in this region has been diminishing rather fast and an indepth study is required to investigate the actual value of water. Moreover, the value of lakewater may not possibly be justified from the point of view of the price at which the Water District is willing to sell its water. It needs to be justified from a larger systems point of view which should incorporate the society.

v) In order to simulate any one combination of the decision variables, the computer program takes about 10 minutes of CPU time in IBM 370 VS system. If a distinct understanding of the system behavior is desired, at least 30 to 40 combinations of the decision variables are required to be simulated. Like any other systems simulation model, this is a major disadvantage of this study. This involves a large amount of computer time and undoubtedly, is expensive. Moreover, the core memory requirement of the simulator is considerably high (276 K) and hence, it might not be possible to execute the program in any medium sized or small computers. In addition to these, the computerized simulation model presents the various cost figures as the present worths basis, but does not analyze the costs or does not plot any vital figures which may be of importance. The final analysis entirely depends upon the analyst himself. He needs to extract final data from the simulator in order to compare various alternative decisions,

vi) The model perhaps puts too much stress on daily rainfall, pan evaporation, evapotranspiration and visitation. The question is: Could it have been possible to achieve somewhat similar results of moderate accuracy by treating these variables as constants, in which case considerable computer time could have been saved. This study is not able to answer this question. However, the main purpose of modeling is to represent the real system as nearly as possible, and from that point of view, this study, though time consuming, may be of more importance.

vii) While generating the daily visitations, this model does not consider the effects of any other special events in the nearby cities. For example, a homecoming football game at Lubbock reduces the daily visitation almost by 80% at the lake. The model is not sensitive to this type of effects from other recreational events.

viii) The model uses the water consumption figures of pecan trees to represent the water requirements of any kind of shade trees. Although this assumption is supported by some irrigation and horticulture experts, it needs to be validated by actual experimentations.

Suggestions for Further Research

This study is an initial step in the direction of systematic analysis of a sewage treatment, collection and irrigation system at a

recreation area. Perhaps the study generated more questions that it answered. While various assumptions on which the model is constructed are not supported by valid assumptions, the analysis process and results of this study do suggest areas of further works. As mentioned previously in Chapter 6, in order to draw some effective conclusions, the study needs to be supported by other research studies. These are:

i) An indepth study of the adequacy of septic tanks treatment in specific areas for specific soils and weather conditions at various loading rates. On-site experimentations are required for this research.

ii) A systematic approach to evaluate the economic value of unpolluted lakewater in specific geographical regions. This research has to incorporate urban dynamics and pollution dynamics along with the socio-political aspects of quality of life, agriculture, recreation, groundwater use and recharges. Such a study undoubtedly will involve a large open loop socioeconomic system model and will need a team of experts from various interdisciplinary areas. Forrester's socioeconomic models on urban dynamics and industrial dynamics are two important references for the suggested study.

iii) A study on the attractiveness of lawns and shade trees at a recreational area, specifically in a semi-arid region. A suggested approach is to collect visitation data at various recreational areas, and then to relate the visitation with the capacity of the reservoir, distances and sizes of the nearby population centers and with the qualities of existing visitation and recreation facilities. This type of study hopefully will be able to identify the contribution of lawns and shade trees on visitation.

Besides the above-mentioned studies, other suggested research is as follows;

i) Maximum and optimum irrigation loads. The maximum amount of treated domestic effluent that may be applied to a given set of plant and soil are not exactly known. Moreover, the response functions of various plants to wastewater irrigation

at different stages of growth need to be evaluated from direct experimentations.

ii) Regulations of wastewater use for irrigation. There is a lack of complete development of laws, statutes and legal principles governing land application activities. An evaluation of federal and state laws, standards and guidelines pertaining to land treatment is essential.

iii) Central sewage treatment and irrigation of agricultural crop. This research should be extended to incorporate small communities and irrigation of agricultural crop with treated effluent. Distinct studies are needed to examine the institutional options as they relate to incentives for farmers and communities to use land treatment for disposing of effluent and sludge. This should include cost sharing, taxation, community grant, pricing of water and sewer services and payment options.

iv) Research should be carried out on the historical and long-term effects that can be measured at existing facilities which have been using effluent applications and/or sludge disposal on land for many years. This research should be directed toward assessment and prediction of groundwater quality resulting from use of effluent for irrigation.

v) Research on markets for effluents and sludges are also essential.

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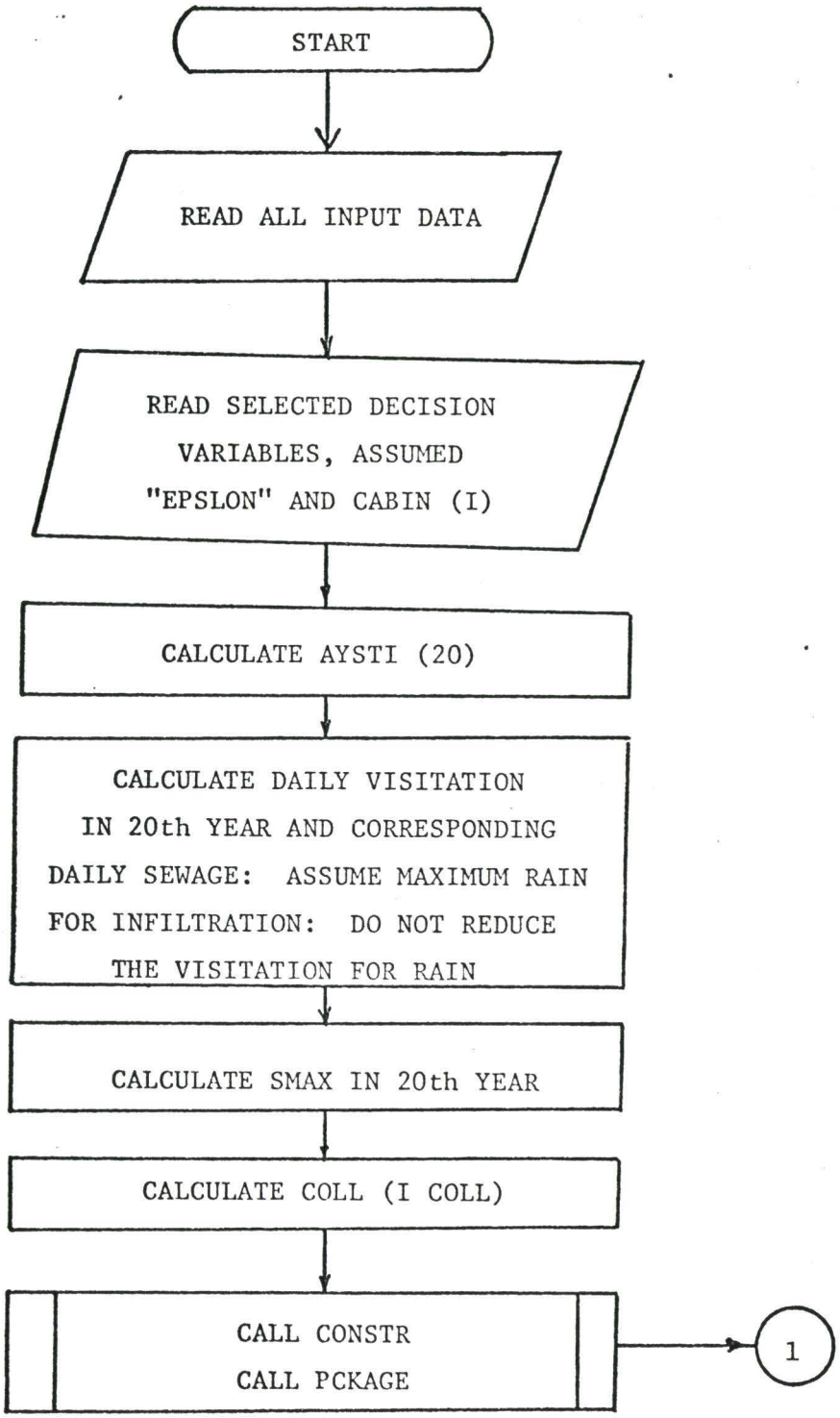
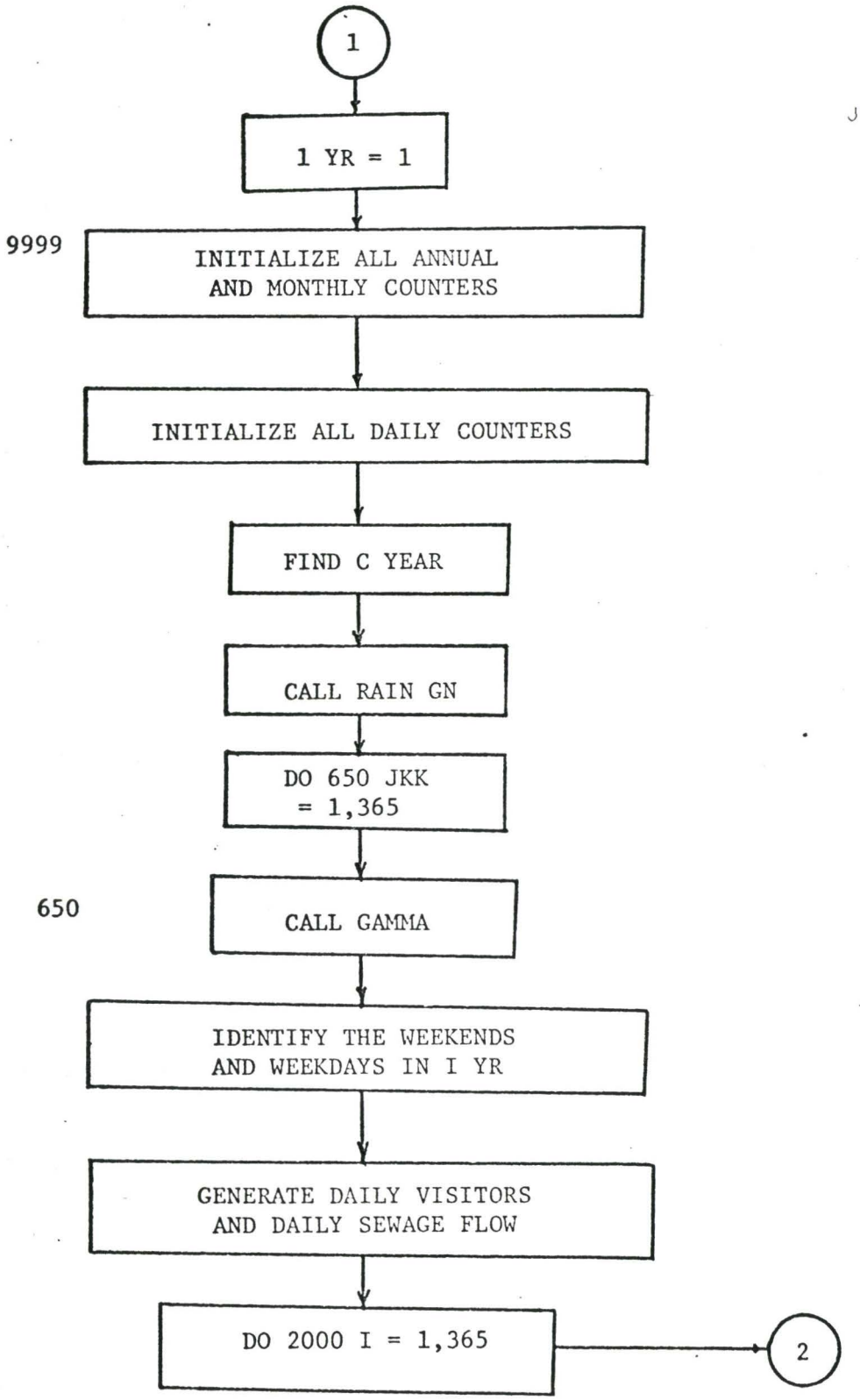
APPENDIX A

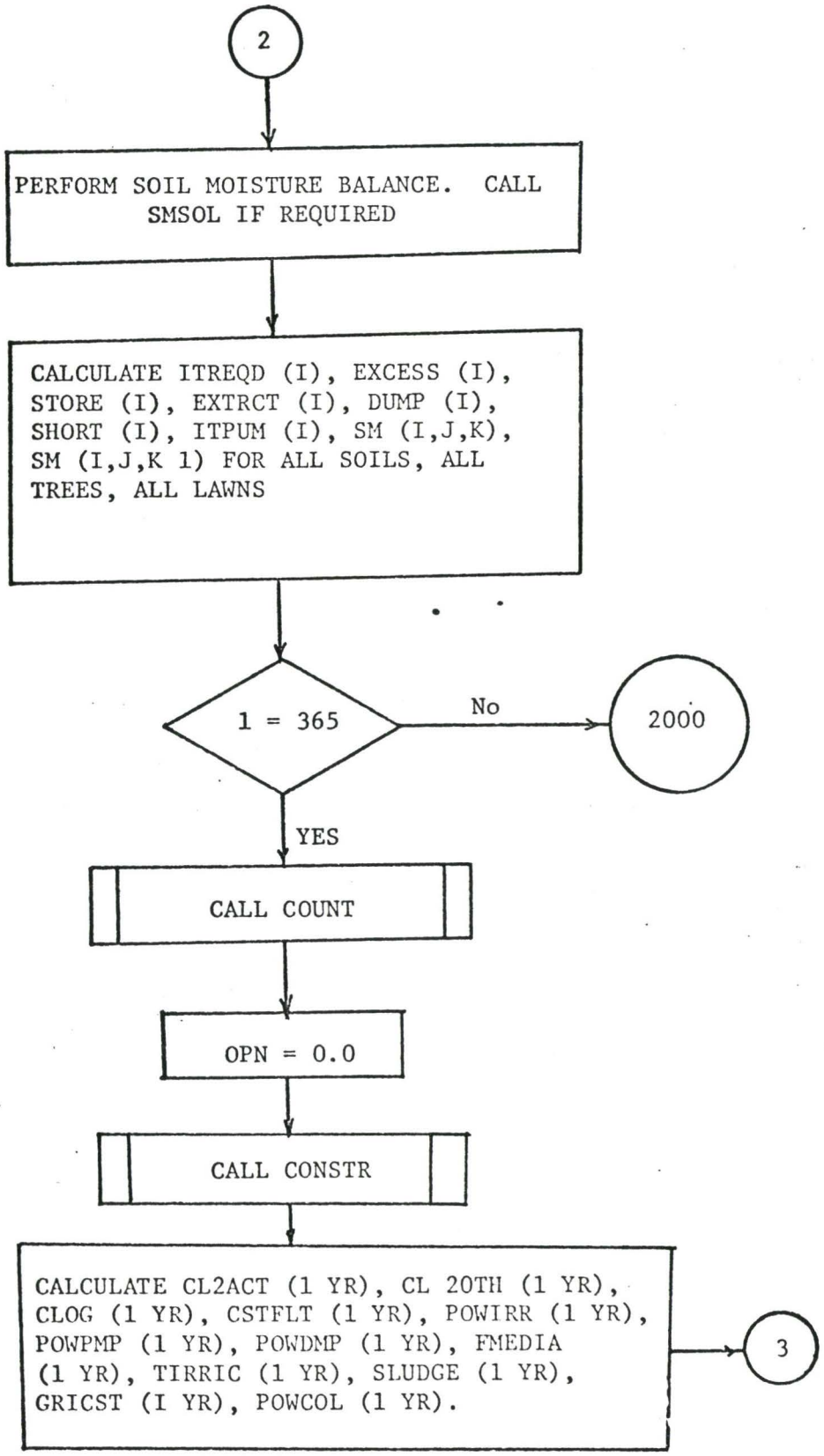
FLOW CHART FOR THE COMPUTER PROGRAM

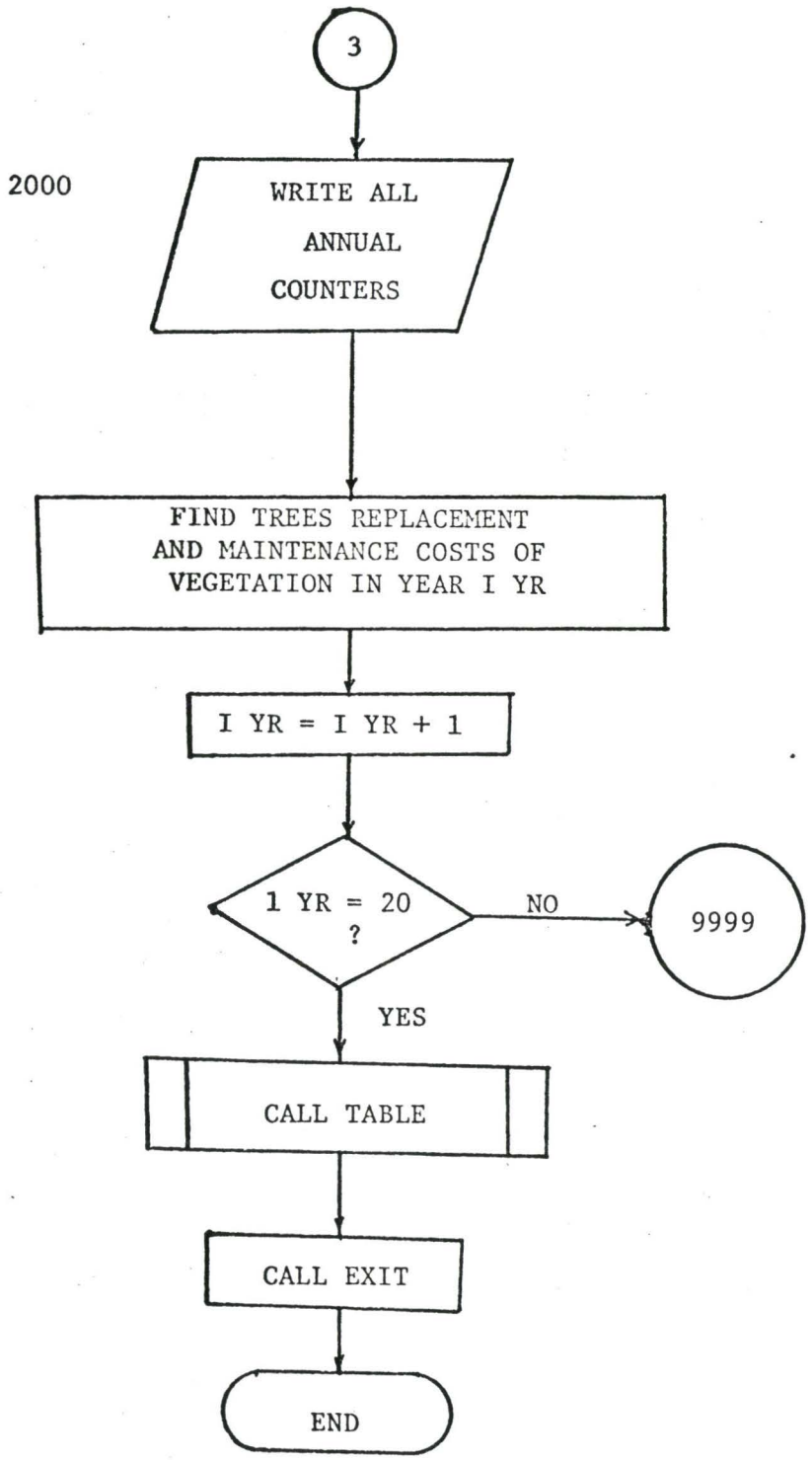
The definitions of the variables used in the following flow charts are as follows:

AVSTI (I)	:	Annual visitation in year I
CABIN (I)	:	Number of vacation homes in year I
CL2ACT (I)	:	Chlorination cost in case of activated sludge plant in year I
CLOG (I)	:	Number of emitters clogged in year I
COL (I)	:	Installation cost for I'th collection system
CONSIR (I)	:	Installation cost for I'th irrigation system
CYEAR (I)	:	Category of annual rainfall
DUMP (I)	:	Gallons of treated effluent disposed in day I
EXCESS (I)	:	Effluent excess in day I
FMEDIA (I)	:	Cost of filtration in year I
GRICST (I)	:	Operation and maintenance cost for the grinder pumps in year I
IYR	:	Year counter
POWIRR (I)	:	Cost of electricity required for irrigation in year I
POWPMP (I)	:	Cost of electricity required for pumping water from secondary source in year I
POWDMP (I)	:	Cost of electricity required for disposing of treated effluent in year I
POWCOL (I)	:	Cost of electricity required by collection system in year I
RIN I	:	Uniformly distributed random number
SM (i,j,k)	:	Soil moisture in day i, soil j under tree variety k


START
READ ALL INPUT DATA
READ SELECTED DECISION VARIABLES, ASSUMED "EPSLON" AND CABIN (I)
CALCULATE AYSTI (20)
CALCULATE DAILY VISITATION IN 20th YEAR AND CORRESPONDING DAILY SEWAGE: ASSUME MAXIMUM RAIN FOR INFILTRATION: DO NOT REDUCE THE VISITATION FOR RAIN
CALCULATE SMAX IN 20th YEAR
CALCULATE COLL (I COLL)
CALL CONSTR
CALL PCKAGE
1

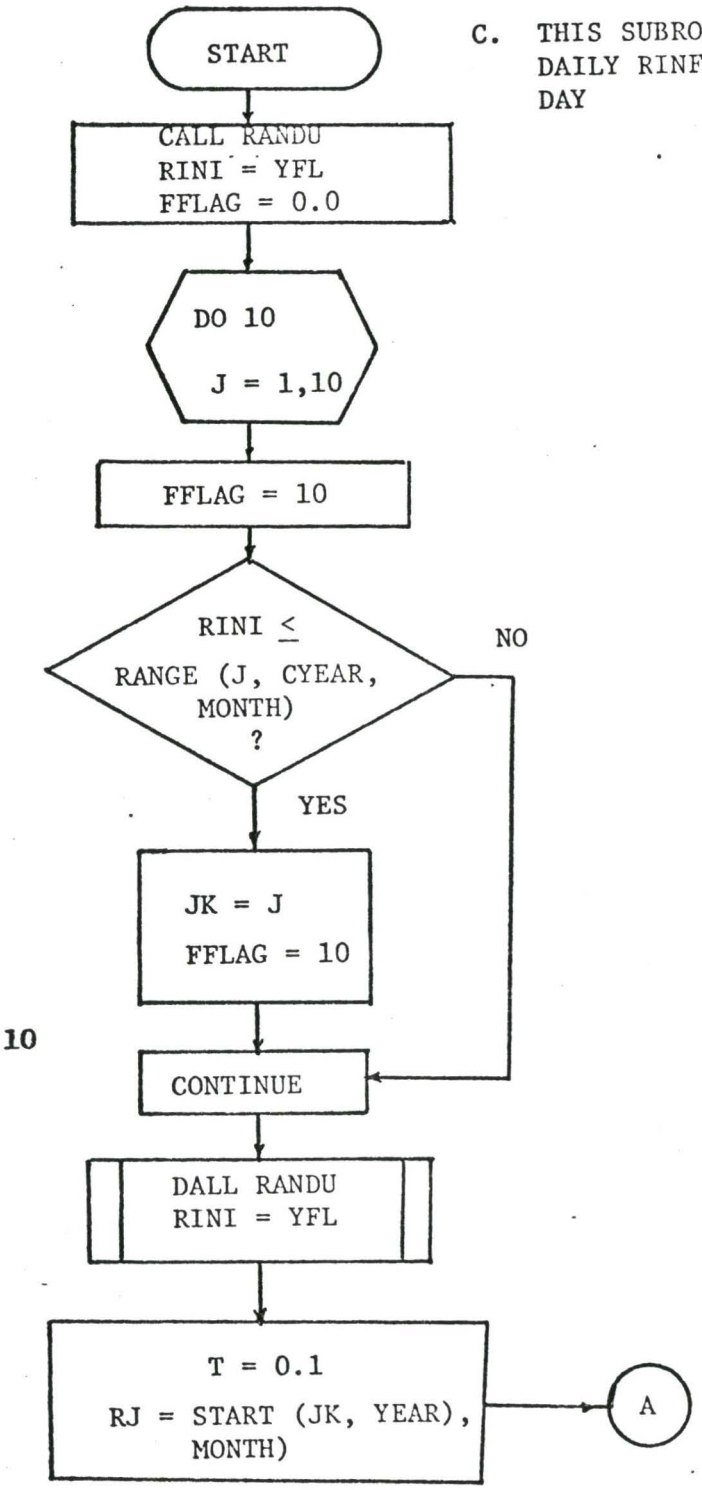

1
1 YR = 1
9999
INITIALIZE ALL ANNUAL AND MONTHLY COUNTERS
INITIALIZE ALL DAILY COUNTERS
FIND C YEAR
CALL RAIN GN
DO 650 JKK = 1,365
650
CALL GAMMA
IDENTIFY THE WEEKENDS AND WEEKDAYS IN I YR
GENERATE DAILY VISITORS AND DAILY SEWAGE FLOW
DO 2000 I = 1,365
2

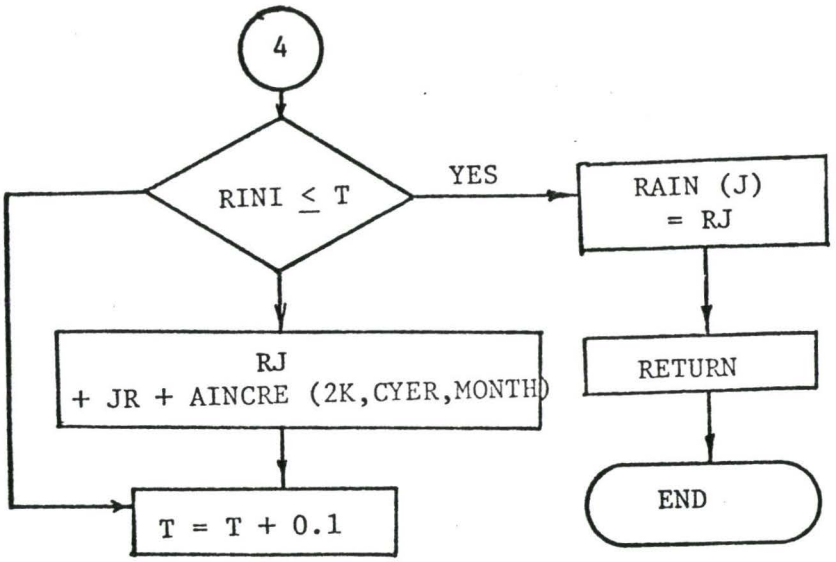

2
PERFORM SOIL MOISTURE BALANCE. CALL SMSOL IF REQUIRED
CALCULATE ITREQD (I), EXCESS (I), STORE (I), EXTRCT (I), DUMP (I), SHORT (I), ITPUM (I), SM (I,J,K), SM (I,J,K 1) FOR ALL SOILS, ALL TREES, ALL LAWNS
1 = 365
No
2000
YES
CALL COUNT
OPN = 0.0
CALL CONSTR
CALCULATE CL2ACT (1 YR), CL 20TH (1 YR), CLOG (1 YR), CSTFLT (1 YR), POWIRR (1 YR), POWPMP (1 YR), POWDMP (1 YR), FMEDIA (1 YR), TIRRIC (1 YR), SLUDGE (1 YR), GRICST (I YR), POWCOL (1 YR).
3


3
2000
WRITE ALL
ANNUAL
COUNTERS
FIND TREES REPLACEMENT
AND MAINTENANCE COSTS OF
VEGETATION IN YEAR I YR
I YR = I YR + 1
1 YR = 20
?
NO
9999
YES
CALL TABLE
CALL EXIT
END

SUBROUTINE AMOUNT

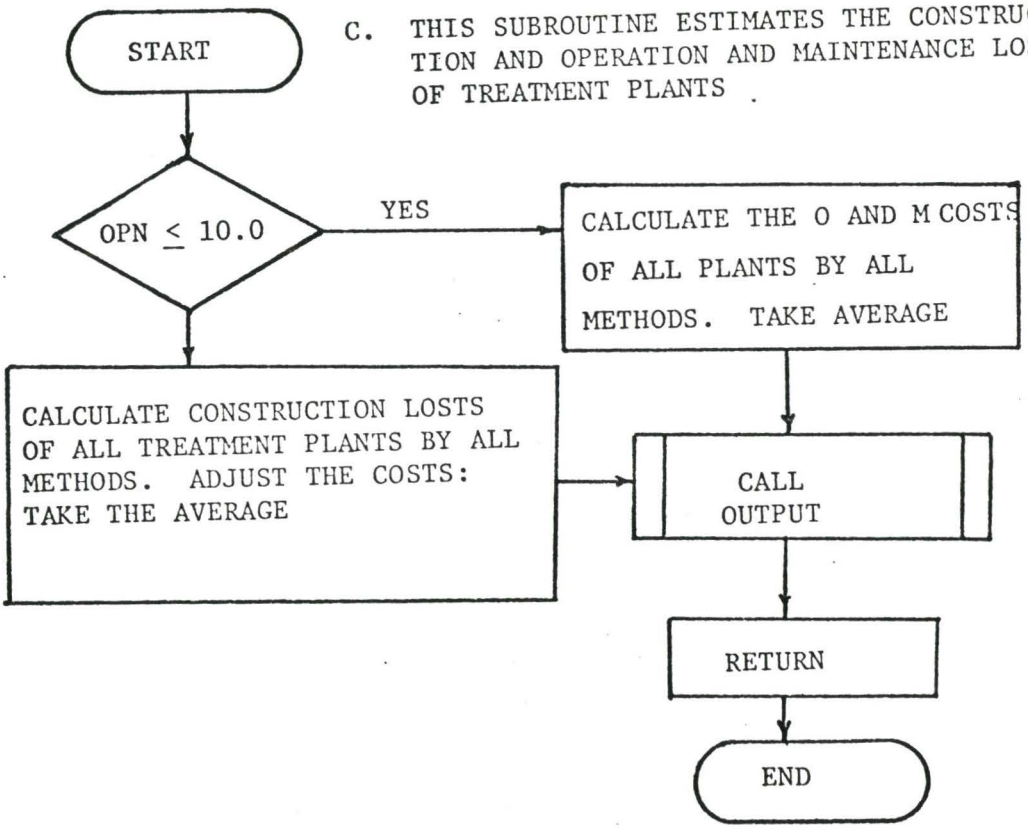
C. THIS SUBROUTINE GENERATES DAILY RINFALL IN A RAINY DAY

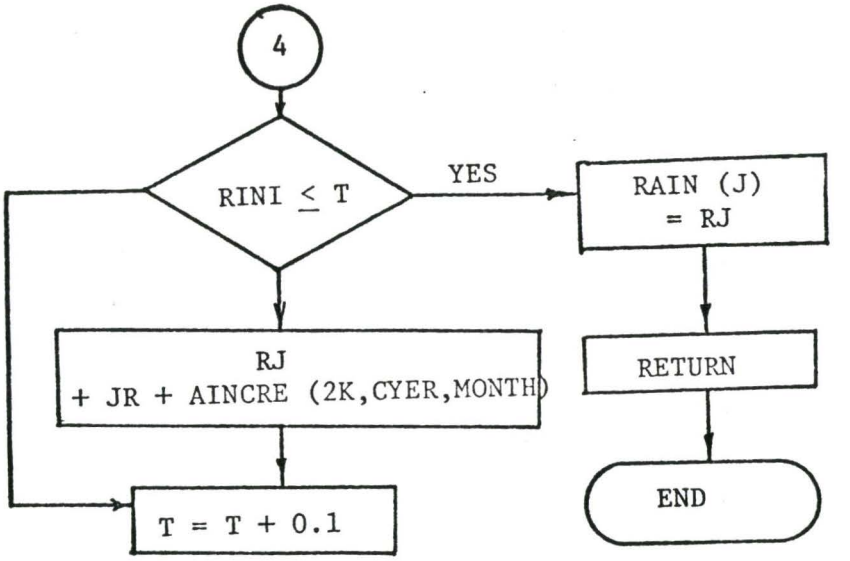




SUBROUTINE CONSTR

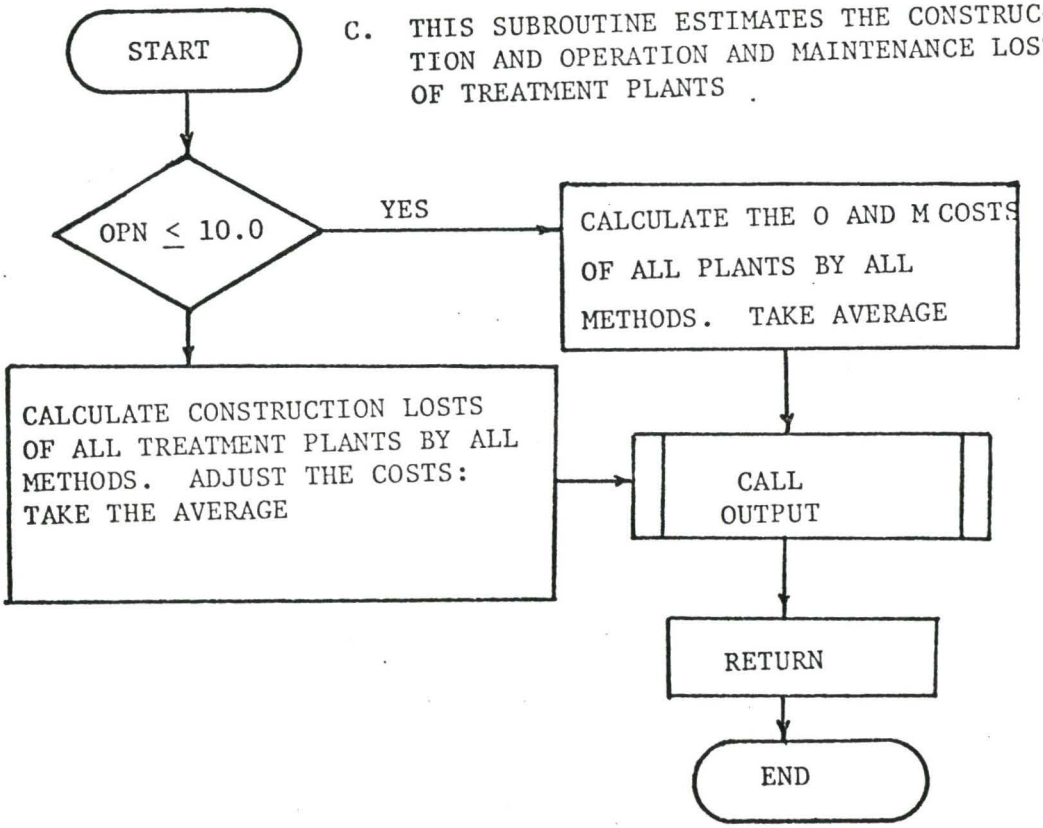
C. THIS SUBROUTINE ESTIMATES THE CONSTRUCTION AND OPERATION AND MAINTENANCE LOSTS OF TREATMENT PLANTS .


START
OPN ≤ 10.0
YES
CALCULATE THE O AND M COSTS OF ALL PLANTS BY ALL METHODS. TAKE AVERAGE
CALCULATE CONSTRUCTION LOSTS OF ALL TREATMENT PLANTS BY ALL METHODS. ADJUST THE COSTS: TAKE THE AVERAGE
CALL OUTPUT
RETURN
END

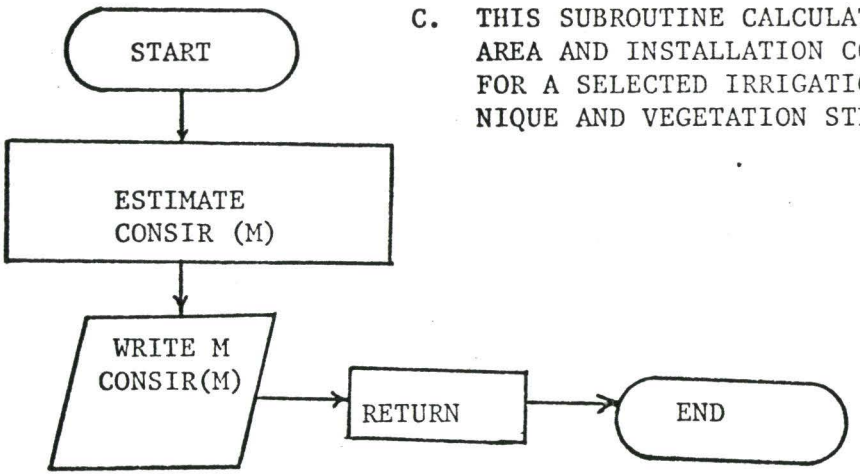


SUBROUTINE CONSTR

C. THIS SUBROUTINE ESTIMATES THE CONSTRUCTION AND OPERATION AND MAINTENANCE LOSTS OF TREATMENT PLANTS .

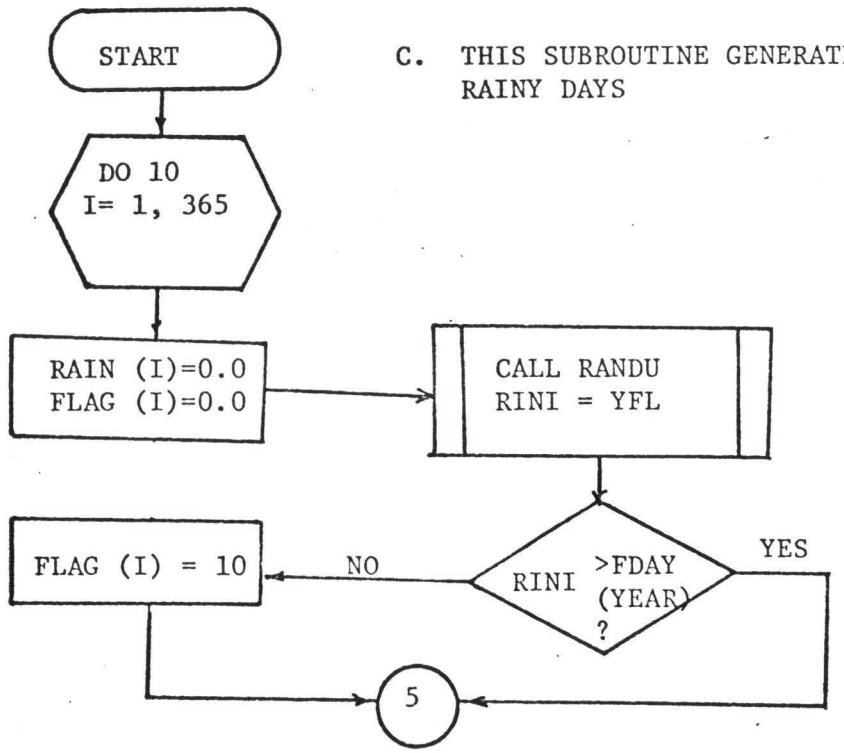

START
OPN ≤ 10.0
YES
CALCULATE THE O AND M COSTS OF ALL PLANTS BY ALL METHODS. TAKE AVERAGE
CALCULATE CONSTRUCTION LOSTS OF ALL TREATMENT PLANTS BY ALL METHODS. ADJUST THE COSTS: TAKE THE AVERAGE
CALL OUTPUT
RETURN
END

SUBROUTINE IRRI1

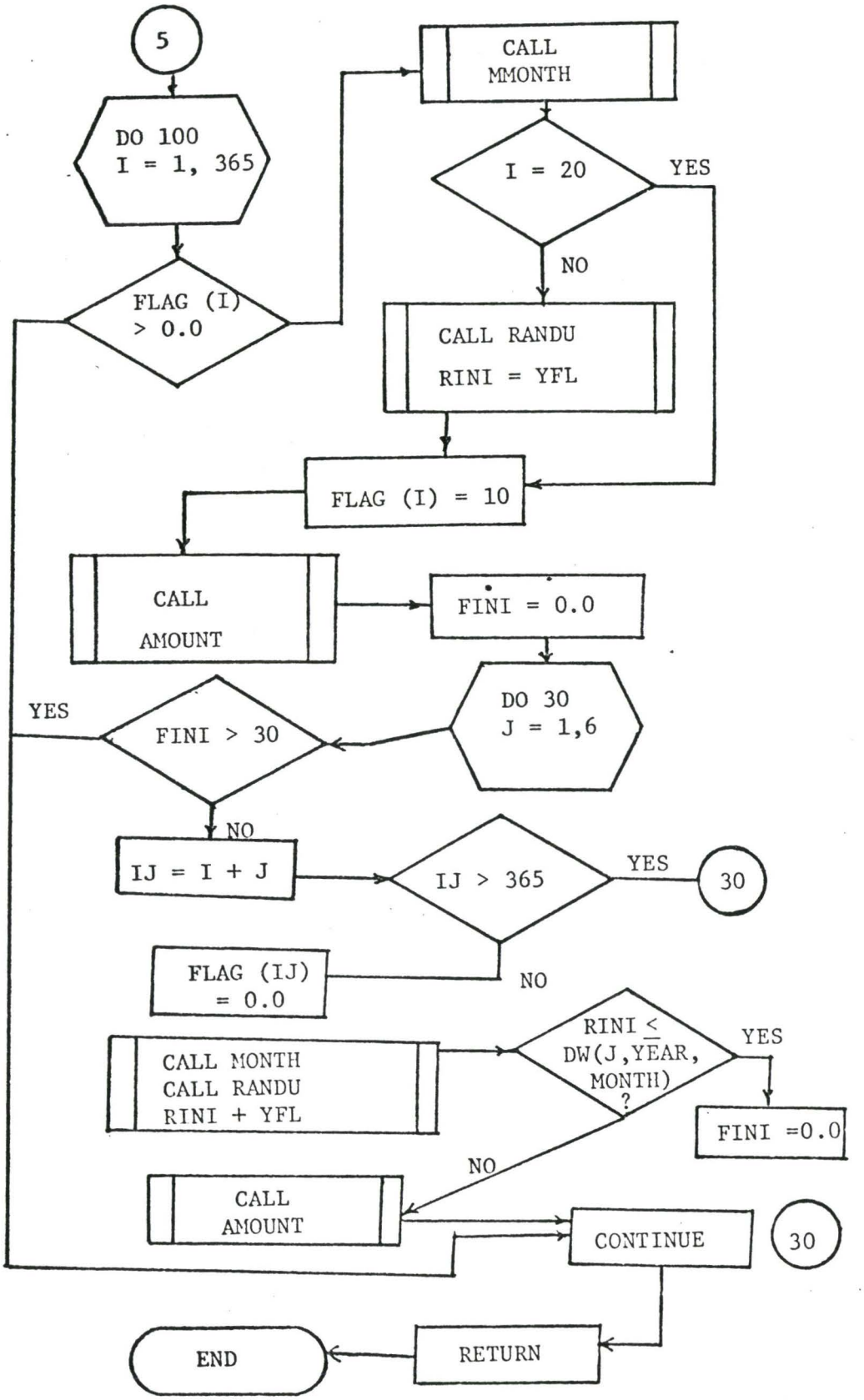


C. THIS SUBROUTINE CALCULATES THE AREA AND INSTALLATION COSTS FOR A SELECTED IRRIGATION TECHNIQUE AND VEGETATION STRATEGY

SUBROUTINE RAINGN



C. THIS SUBROUTINE GENERATES THE RAINY DAYS


5
DO 100
I = 1, 365
FLAG (I)
> 0.0
CALL
MMONTH
I = 20
YES
NO
CALL RANDU
RINI = YFL
FLAG (I) = 10
CALL
AMOUNT
FINI = 0.0
DO 30
J = 1,6
YES
FINI > 30
NO
IJ = I + J
IJ > 365
YES
30
FLAG (IJ)
= 0.0
NO
CALL MONTH
CALL RANDU
RINI + YFL
RINI ≤
DW(J,YEAR,
MONTH)
?
YES
FINI =0.0
NO
CALL
AMOUNT
CONTINUE
30
END
RETURN

SUBROUTINE COUNT

C. This subroutine keeps the counts of all related daily counters.

SUBROUTINE FINAL

C. This subroutine tabulates the final costs of benefit figures.

SUBROUTINE GAMMA

C. This subroutine generates random gamma variates.

SUBROUTINE RANDU

C. This subroutine generates uniformely distributed random variate

SUBROUTINE SMSOL

C. This subroutine is called only when the volume of total effluent available in a day is not sufficient to irrigate all the fields to maximum permittable levels.

SUBROUTINE TABLE

C. This subroutine tabulates the annual summary of cost and benefit figures.

APPENDIX B

DOCUMENTATION OF THE COMPUTER PROGRAM

Programmer	:	Mesbah V. Ahmed
Advisor	:	Dr. Arun G. Walvekar
Machine used	:	IBM 307 VS
Language	:	FORTRAN IV
Approximate CPU time	:	11 minutes for one set of decision variables
Core requirement	:	272 K

The listing of the entire program is given in next section.

```
      REAL KWH
      INTEGER CYEAR
C*****************************************************
C*                                                   *
C*                THE MAIN ROUTINE                   *
C*                                                   *
C*****************************************************
C*                                                   *
C*          PROGRAMMER:MESRAM U. AHMED               *
C*          ADVISORS: DR. ARUN G. MALVEKAR           *
C*                    DEPT. OF I.E.  T.T.U.          *
C*                DR. KENNETH B. YOUNG               *
C*                    DEPT. OF AG.ECO. T.T.U.        *
C* THE MAIN ROUTINE READS ALL THE INPUT DATA,        *
C* SIMULATES THE MOISTURE BALANCE AND CALLS THE      *
C* SUBROUTINES, WHENEVER NECESSARY, TO REACH THE     *
C* FINAL COST FIGURES OF DIFFERENT STRATEGIES ON     *
C* TREATMENT, COLLECTION AND IRRIGATION              *
C*                                                   *
C*****************************************************
      DIMENSION SLUDGE(20),GRCONS(365),GRCOEFF(2),EFFIRR(2),PUMPGN(365),
     1CL2ACT(2),CL2OTH(2),ACHL(2),BCHL(2),CLOG(20),CSTFLT(20),POWIRR(2
     10),PCWDAP(20),PUMPAP(20),PMERIA(20),TIRRIC(20,2),
     2GRINDC(20),GRIND(20),PCHLOR(20),FILTR(365)
      DIMENSION AVST1(2),CAB1N(20),TLMAX(20)
      DIMENSION AVMP(12),W1(12),W2(12),SOURCE(20),FLOW(20),ISAT(12),
     1WKEND(12),IWKEND(12),WKDAY(12),DAYVIS(300),CABVIS(300),CAMP(3800),
     1 TRAIN(3900),SEWAGE(380),ISUN(12),ACL(2),
     1BCL(2),COLL(2)
      DIMENSION PCYEAR(3)
      DIMENSION PRAIN(2),
     1P3(3,2)),TPEV(365,3),*TPEV(365),PEV(365,3,3),
     1*TFROD(365),TFROD(365,3),REQ(365,3,3),
     1AREA(3),COSTRV(365),*ACCESS(365),WATER(365),STORE(366),
     1FXTRA(365),AWAT(2,365),
     1PUMP(365,3,3),TPUMP(365,3)
      DIMENSION AL(12),EFF(12)
      COMMON/BLOCK8/CONSIR(5),AIRR(5),BIRR(5)
      COMMON/BLOCK4/IUT3
      COMMON/BLOCK5/PEI(365)
      COMMON/BLOCK6/RAIN(365)
      COMMON/BLOCK7/DUMP(365),TPUM(365)
      COMMON/BLOCK3/CAPDRY(3,20),SC(3),WHC(3),SM(365,3,3),
     1APPLY(365,3,3),TREES(3,3),SMEST(3,3),SMLST(3,3),FLAGM(3,3)
      COMMON/BLOCK1/SOLY(3),GC(3,12),RANGE(12,3,12),
     1STORE(10,3,12),*(36,3,12),RINCAP(10,3,12)
      COMMON/BLOCK2/RUN(3),SI(5),A2(5),T(5),REMS(5),CX1(5),CX2(5),C11(5),
     1C12(5),C22(5),WP(12),FY(12),XLIMIT(5),XLIMIT1(5),CN(5),COEFF(20),
     1EP(20),COST(20),DCOST(20),  CMICH(6),CONSM(6),APPICH(6),COEF(20),
     1*P(2),APC,ICITY,JYEAR,AVMAT,AENH,CONTRC(7,20),TACONS(7),CPN
      COMMON/BLOCK9/VCAPME(12,20),VDAYMI(12,20),VCAMP(12,20),VTRLMI(12,20),
     1AYV(20),*CAMVI(20),*TRLVI(20),ANCAPY(23),REVCOV(365),TREEV(23),
     1TREVE(23),FEVMON(12,23)
      COMMON/BLOCK15/SEWGYR(20),TOT(20),TPI(20)
      COMMON/BLOCK17/OUT11
      DIMENSION CACL(2),TRUNK(5,20),REPLTS(20)
      DIMENSION TF(10,18)
      RATRST=6.
C
C        FILTR(I) : INFILTRATION IN GALLONS IN I*TH DAY
C        AFILTR : MAXIMUM POSSIBLE INFILTRATION IN GALLONS PER MILE OF
C        COLLECTION ASSUMED TO BE 3000 GALLONS PER MILE AT 1.2 INCHES OF
C        RAIN.
C        FILCOE : INFILTRATION COEFFICIENT FOR COLLECTION SYSTEM.= 1.
C        PIP GRAVITY AND W FOR PRESSURE
C        PRICOE : EXTRA COLLECTION PIPE REQD CABIN RELATIVE TO ORIGINAL
C        NUMBER OF CABINS.ASSUMED TO BE 0.4 HERE
C        PLINE : TOTAL LENGTH OF COLLECTION PIPE REQUIRED WITHOUT ANY
C        FURTHER INCREASE IN SUMMER HOMES. CALCULATED TO BE
C        APPROXIMATELY 9.5 MILES.
C        ZROVE : AMOUNT OF RAIN AT WHICH DAILY VISITATION ARE ASSUMED
C        TO BE ZERO.
      NRUN=1
      DPW=20.0
      SMINI=.6
      VISOUT=1.
C     OUT1.LE.0.0    INDICATES THAT DAILY RAIN AND PANEVAPORATION
C     OUTPUT DESIRED
C     OUT2.LE.0.0    INDICATES THAT DAILY SIMULATED SOIL MOISTURE BALANCE
C     INFORMATIONS REQUIRED
C     OUT3.LE.0.0    INDICATES THAT NUMERICAL ITERATIONS FOR IRRIGATION
C     DISTRIBUTION FROM SUBROUTINE SMSOL ARE DESIRED
C     OUT4.LE.0.0    INDICATES THAT INFORMATIONS ON FINAL ITERATION IN
C     IRRIGATION DISTRIBUTION IS DESIRED
C     OUT5.GT.0.0 INDICATES THAT DAILY VISITATION INFORMATIONS REQD.
C     OUT6.GT.0.0    MEANS THAT DAILY INFILTRATION OUTPUT DESIRED
C     OUT11.GT.0.0 : DETAILS OF OPN. AND CONSTRUCTION COST NOT NEEDED
      READ(5,13)OUT1,OUT2,OUT3,OUT4,OUT5,OUT6,OUT7,OUT8,OUT9,OUT10
   13 FORMAT(10F8.2)
      READ(5,13)OUT11
      READ(5,31)*IRRI,*COLL
   31 FORMAT(5I10)
      IF(IRRI.EQ.1) GO TO 33
      WRITE(6,32) IRRI
   32 FORMAT(1H1,10X,'IRRIGATION SYSTEM IS AUTOMATED SPRINKLER',10X,I5)
      GO TO 35
   33 WRITE(6,34)IRRI
   34 FORMAT(1H1,10X,'IRRIGATION SYSTEM IS AUTO. SUBMATIC',20X,I5)
   35 IF(COLL.EQ.1) GO TO 37
      WRITE(6,36)COLL
   36 FORMAT(///,10X,'PRESSURIZED COLLECTION SYSTEM',20X,I5)
      GO TO 44
   37 WRITE(6,38)COLL
   38 FORMAT(///,10X,'GRAVITY COLLECTION SYSTEM',10X,I5)
   44 READ(5,12)(GRCOEFF(I),I=1,12)
      WRITE(6,39)(GRCOEFF(I),I=1,12)
   39 FORMAT(1H1,5X,'PAN COEFFICIENTS FOR GEASS IN DIFFERENT MONTHS',2X
     1,12(F4.3,1X))
      READ(5,7) FILCOE
      WRITE(6,7) FILCOE
      READ(5,143)(GRINDP(I),I=1,20)
      WRITE(6,513)(GRINDP(I),I=1,20)
   51 FORMAT(1H1,5X,'GRINDER PUMPS=',2X,20(F3.0,1X))
C        SLUCST: COST PER TON OF SLUDGE TO CARRY FROM SLUDGE BED TO
C        DISPOSAL SITE. INCLUDES LOADING COST,LABOR AND GASOLINE COST.
C     .  IN $/TON: ASSUMED DISTANCE TO DISPOSAL SITE, 5 MILES.
C        GRIPR: MAINTENANCE COST PER GRINDER PUMP,$/YEAR
C        KWH: POWER COST,$/KWH
C        ACHL(1): CHLORINATION NEEDED: SUBMATIC: ACTIVATED, MG/LITER
C        ACHL(2): CHLORINATION NEEDED: SPRINKLER: ACTIVATED,MG/LITER
C        BCHL(1): CHLORINATION NEEDED: SUBMATIC: OTHER TREATMENT PLANTS
C        BCHL(2): CHLORINATION NEEDED: SPRINKLER: OTHER TREATMENT PLANTS
C        PCL2: COST OF CHLORINE: IN $/LB
C        CLOPCT: PERCENT OF TOTAL EMITTER ASSUMED TO BE CLOGGED
C        COSTEM: COST OF REPLACING A CLOGGED EMITTER
C        CLNHR: LABOR REQD FOR MANUAL CLEANING OF THE SCREEN FILTERS FOR
C        SUBMATIC.(IN HOUR)
C        HRATE: $/HR FOR CLEANING THE SCREENS
C        CART: NUMBER OF CARTIDGE IN THE SAND CARTRIDGE FILTER
C        CARTPR: COST FOR REPLACING THE CARTIDGE
C        SILICA: NUMBER OF SILICA BAGS IN THE SAND BED FILTER
C        SILICAPR: PRICE PER BAG OF SILICA BAG
      READ(5,12)SLUCST,GRIPR,KWH,ACHL(1),ACHL(2),BCHL(1),BCHL(2),PCL2
     1 TREES= COST OF A TREE IN $/SQ. INCH OF TRUNK AREA
C     GGRM=MAINTENANCE COST PER GRINDER
      READ(5,12)CLOPCT,COSTEM,TREES,HRATE,GGRM,CARTPR,SILIPR
      WRITE(6,52)SLUCST,GRIPR,KWH,ACHL(1),ACHL(2),BCHL(1),BCHL(2),PCL2
   52 FORMAT(///,2X,'SLUCST $/TON=',F4.1,1X,'GRIPR=$',F4.1,1X,'KWH=$',F4.
     12,1X,'ACHL1=MG/LT',F3.0,1X,'ACHL2=',F3.0,1X,'BCHL1=',F3.0,1X,'BCHL
     12=',F3.0,1X,'PCL2=$/LB',F5.4)
      WRITE(6,53)CLOPCT,COSTEM,TREES,HRATE,GGRM,CARTPR,SILIPR
   53 FORMAT(///,2X,'CLOPCT=',F5.2,1X,'COSTEM=$',F4.2,1X,'TREES  ',F4.1,
     1'HRATE=$/HR',F4.2,1X,'GGRM=',F4.0,1X,'CARTPR=',F3.1,1X,'SILIPR=$/
     13AG',F4.2)
      READ(5,7)EFFIRR(2),EFFIR(1)
      WRITE(6,54)EFFIRR(2),EFFIRR(1)
   54 FORMAT(///,2X,'IRRIGATION EFFICIENCY FACTORS : SPRINKLER =',F3.2,10
     1X,'SUBMATIC =',F4.1)
      READ(5,7) PMAX
      WRITE(6,73)PMAX
      READ(5,7) AFILTR,PLINE,PERCOE
      WRITE(6,73)AFILTR,PLINE,PERCOE
      READ(5,153)FEEWD,FEESAT,CABLTS,TRLFES,CAMFEE
      WRITE(6,163)FEEWD,FEESAT,CABLTS,TRLFES,CAMFEE
      READ(5,11)YEAR,IFST,BASEYR,VFSTYR,SLOPE,DIFFY0
    1 FORMAT(F10.2,I1),4E1.2)
      WRITE(6,1)YEAR,IFST,BASEYR,VFSTYR,SLOPE
      READ(5,2)(AVMP(I),I=1,12)
    2 FORMAT(8F10.5)
      WRITE(6,2)(AVMP(I),I=1,12)
      READ(5,12) (W1(I),I=1,12),(W2(I),I=1,12)
   12 FORMAT(8F10.6)
      WRITE(6,12)(W1(I),I=1,12),(W2(I),I=1,12)
      READ(5,3) (SOURCE(I),(SOURCE(I),I=1,ISOURCE)
    3 FORMAT(1I10,7F10.2)
      WRITE(6,3) ISOURCE,(SOURCE(I),I=1,ISOURCE)
      READ(5,7) (FLOW(I),I=1,ISOURCE)
    7 FORMAT(8F10.2)
      WRITE(6,7)(FLOW(I),I=1,ISOURCE)
      READ(5,14)(CAB1N(I),I=1,10)
      READ(5,14)(CAB1N(I),I=11,20)
   14 FORMAT(10F8.1)
      WRITE(6,15)(CAB1N(I),I=1,20)
   15 FORMAT(///,2X,'CABIN DEVELOPMENT',20(F4.0,1X))
      READ(5,14)(TLMAX(I),I=1,10)
      READ(5,14)(TLMAX(I),I=11,20)
      WRITE(6,16)(TLMAX(I),I=1,20)
   16 FORMAT(///,2X,'TRLR DEVELOPMENT',2)(F4.0,1X))
      READ(5,4) EPSLN,CAMPER,CABFLO,VISFLO,TRLPER,TRLFLO,CAMPER,CAMFLO
    4 FORMAT(8F10.4)
      WRITE(6,4) EPSLN,CAEPER,CABFLO,VISFLO,TRLPER,TRLFLO,CAMPER,CAMFLO
      AEPS=(EPSLN-1.)*100.
      WRITE(6,161)AEPS
      SILICA=4.+(0.025*AEPS)
      CART=24.+(0.15*AEPS)
      CLNHR=0.2+(.0125*AEPS)
      WRITE(6,155) CLNHR,CART,SILICA
  155 FORMAT(///,'CLNHR=',F5.2,2X,'CARTIDGES=',F5.1,2X,'SILICA BAG=',F5.1)
      READ(5,161) ROPIN
  161 FORMAT(F10.2)
      WRITE(6,161)ROPIN
      SKIP=0.0
      READ(5,162) ICITY,JYEAR,APC
      WRITE(6,162) ICITY,JYEAR,APC
  162 FORMAT(2I10,F10.3)
      READ(5,163) (APC(I),I=1,20)
      WRITE(6,163) (APC(I),I=1,20)
  163 FORMAT(8F10.2)
      DO 165 I=1,5
      READ(5,8) B0(I),B1(I),B2(I),T(I),REMS(I),CX1(I),CX2(I),C11(I),
     1C12(I),C22(I),CN(I)
    8 FORMAT(8F10.5)
  165 CONTINUE
      READ(5,142)(COEF(I),I=1,20)
  142 FORMAT(10F8.1)
      READ(5,143)(EP(I),I=1,20)
  143 FORMAT(10F8.5)
      READ(5,145) AVNAT
  145 FORMAT(F10.3)
      READ(5,142) (DEF(I),I=1,20)
      READ(5,143)(OP(I),I=1,20)
      READ(5,145) AENH
      READ(5,250)(CONSM(I),I=1,6)
  250 FORMAT(6F10.1)
      READ(5,251)(RMICH(I),I=1,6)
  251 FORMAT(10F10.7)
      READ(5,260) ACL(1),ACL(2),BCL(1),BCL(2),CACL(1),CACL(2)
  260 FORMAT(4F15.3,2F10.2)
C*****************************************************************
C*                                                               *
C*     ACL(1)= 'A' COEFFICIENT OF (B4C*AEPS+A(CABIN) AT  NPLNYR:GRAVITY *
C*     ACL(2)= 'A' COEFFICIENT OF (B4C*AEPS+A(CABIN) AT  NPLNYR:PRESSURE*
C*     BCL(1) AND BCL(2) ARE THE 'B' COEFFICIENTS RESPECTIVELY           *
C*     CACL(1) AND CACL(2) ARE THE 'C' COEFFICIENTS RESPECTIVELY         *
C*                                                               *
C*****************************************************************
      WRITE(6,1015)
      WRITE(6,1016)
      WRITE(6,262)
  262 FORMAT(5X,60HP EQUATIONS FOR INSTALLATION COST : COLLECTION SYSTEM
     1      *)
      WRITE(6,270) ACL(1),BCL(1),CACL(1)
  270 FORMAT(////,5X,'GRAVITY COLLECTION COST=',F12.2,'*# OF HOMES IN PIN
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     1AL YP   + (',F10.1,'AEPS)=',F8.2)
      WRITE(6,275) ACL(2),PCL(2),CACL(2)
  275 FORMAT(////,5X,'PRESSRE COLLECTION COST=',F12.2,'# OF HOMES IN FIN
     1AL YP   + (',F10.1,'AEPS)=',F8.2)
      DO 285 I=1,5
  285 CONSIP(I)=0.0
C         CONSIP(1)   =  CONSTRUCTION COST : SUBMATIC : 5*5: AUTO
C         CONSIP(2)   =  CONSTRUCTION COST : SUBMATIC : 30*30 : AUTO
C         CONSIP(3)   =  CONSTRUCTION COST : SUBMATIC : 40*40 : AUTO
C         CONSIP(4)   =  CONSTRUCTION COST : SPRINKLER : 40*40 : MANUAL
C         CONSIP(5)   =  CONSTRUCTION COST : SPRINKLER : 40*40 : AUTO
C         AIRPI(I)=  SLOPE OF I'TH IRRIGATION COST EQUQTION
C         BIRPI(I)=  INTERCEPT OF I'TH IRRIGATION COST EQUATION
      READ(5,290) (AIRRI(I),I=1,5)
      READ(5,290) (BIPPI(I),I=1,5)
  290 FORMAT(5F10.3)
      DO 300 I=1,5
      WRITE(6,295) I,AIRRI(I),RIPPI(I)
  295 FORMAT(//,2X,'IRRIGATION TECHNIQUE=',I3,2X,'SLOPE=',F10.2,2X,'INTE
     1RCEPT=',F10.2)
  300 CONTINUE
      WRITE(6,1016)
      WRITE(6,1017)
      READ(5,501)(PCYEAR(I),I=1,3)
  501 FORMAT(3F10.6)
      READ(5,501)(FDAY(I),I=1,3)
      DO 505 I=1,3
  505 READ(5,506)(DD(I,J),J=1,12)
  506 FORMAT(12F6.4)
      DO 510 J=1,3
      DO 510 I=1,6
  510 READ(5,506)(DW(I,J,K),K=1,12)
      DO 520 J=1,3
      DO 520 I=1,10
      READ(5,506)(RANGE(I,J,K),K=1,12)
  520 CONTINUE
      DO 580 J=1,3
      DO 580 I=1,10
      READ(5,506)(START(I,J,K),K=1,12)
  580 CONTINUE
      DO 590 J=1,3
      DO 590 I=1,10
      READ(5,506)(AINCRE(I,J,K),K=1,12)
  590 CONTINUE
      READ(5,512) RITE,RITERN
  512 FORMAT(2F10.3)
      DO 605 JK=1,12
  605 READ(5,600) AL(JK),BET(JK)
  600 FORMAT(2F10.4)
      READ(5,610) STAPI
      READ(5,400)NPLNYR,NVARI,NSOIL
 4001 FORMAT(3II)
      DO 1005 IVART=1,NVARI
 1005 READ(5,1003)(ID(IVARI,III),III=1,NPLNYR)
 1003 FORMAT(1I1,3)
      DO 1006 IVART=1,NVARI
 1006 READ(5,1003)(TRUNK(IVARI,III),III=1,NPLNYR)
C     TRUNK(I,J)=CROSS SECTIONAL AREA OF J'TH TYPE TREE IN I'TH YR SOIN
      READ(5,1010)(FC(ISOIL),WHC(ISOIL),ISOIL=1,3)
 1010 FORMAT(4F10.3)
  610 FORMAT(F10.3)
      WRITE(6,1015)
      WRITE(6,1016)
      WRITE(6,1020)
 1020 FORMAT(5X,60H*   ASSUMED CANOPY GROWTH: RADIUS IN FT
     1      *)
      WRITE(6,1016)
      WRITE(6,1017)
      WRITE(6,1018)NPLNYR
 1018 FORMAT(///,2X,'YEAR OF GROWTH=  1    2    3    4    5    6    7
     1 8    9    10   11   12   13   14   15   16   17   18   19   20 *,
     1I5)
      WRITE(6,1019)
 1019 FORMAT(2X,9HTREE TYPE)
      DO 1025 IVART=1,NVARI
 1025 WRITE(6,1027) IVARI,(ID(IVARI,III),III=1,NPLNYR)
 1027 FORMAT(/,8X,I5,5X,20(F6.1,1X))
      WRITE(6,1022)
 1022 FORMAT(///,60H* ASSUMED GROWTH IN TRUNK X-SECTION IN SQ. INCH
     1      *)
      WRITE(6,1018)NPLNYR
      WRITE(6,1019)
      DO 1029 IVART=1,NVARI
 1029 WRITE(6,1027) IVARI,(TRUNK(IVARI,III),III=1,NPLNYR)
C     ***************************************************
C     *                                                 *
C     *   DUMP(I)      = GALLONS OF EFFLUENT WHICH NEED TO BE*
C     *                  DRAINED OFF DUE TO UNAVAILABILITY  *
C     *                  OF STORAGE IN I'TH DAY             *
C     *   EXTRCT(I)    = GALLONS OF EFFLUENT TO BE TAKEN FROM*
C     *                  THE STORAGE IN I'TH DAY            *
C     *   AWATER(I)    = TOTAL GALLONS OF EFFLUENT AVAILABLE*
C     *                  FROM SEWAGE AND STORAGE IN I'TH DAY *
C     *   AII,J)       = 'A' COEFFICIENTS OF 'AX+B'       *
C     *                  EXPRESSION FOR I'TH SOIL, J'TH TREE *
C     *   BII,J)       = B COEFFICIENTS OF AX+B           *
C     *   LOSTRN(I)    = AMOUNT OF RAIN LOST IN I'TH DAY,INCH*
C     *                                                   *
C     ***************************************************
      WRITE(6,1015)
      WRITE(6,1016)
      WRITE(6,1024)
 1024 FORMAT(5X,60H*                  SOIL CHARACTERSTICS
     1      *)
      WRITE(6,1016)
      WRITE(6,1017)
      WRITE(6,2010)
 2013 FORMAT(2X,'I',5X,'FIELD CAPACITY      WATER HOLDING CAPACITY:INCHES  I
      DO 2011 NS=1,NSOIL
 2011 WRITE(6,2012)NS,FC(NS),WHC(NS)
 2012 FORMAT(8X,'SOIL TYPE=',I2,6X,F6.2,15X,F6.2)
      DO 530 I=1,3
      WRITE(6,523) I,PCYEAR(I)
  523 FORMAT(////,5X,'CYEAR=',I2,5X,'PCYEAR=',F8.6)
  530 CONTINUE
      WRITE(6,535)(FDAY(I),I=1,3)
  535 FORMAT(///,2X,'FDAY',2X,3(F6.5,1X))
      DO 525 I=1,3
  525 WRITE(6,526)I,(DD(I,J),J=1,12)
  526 FORMAT(/,2X,'CYEAR=',I3,2X,'DD',2X,12(F6.4,1X))
      DO 528 J=1,3
      DO 528 I=1,6
  528 WRITE(6,527)I,J,(DW(I,J,K),K=1,12)
  527 FORMAT(2X,'WET SEQ=',I2,2X,'CYEAR',I2,2X,'DW',2X,12(F6.4,1X))
      DO 540 J=1,3
      DO 540 I=1,10
      WRITE(6,531)I,J,(RANGE(I,J,K),K=1,12)
  531 FORMAT(2X,'STEP=',I2,'CYEAR=',I2,'RANGE',2X,12(F6.4,1X))
  540 CONTINUE
      DO 585 J=1,3
      DO 585 I=1,10
      WRITE(6,532)I,J,(STAPTI(I,J,K),K=1,12)
  532 FORMAT(2X,'STEP=',I2,'CYEAR=',I2,'START',2X,12(F6.4,1X))
  585 CONTINUE
      DO 595 J=1,3
      DO 595 I=1,10
      WRITE(6,533)I,J,(AINCRE(I,J,K),K=1,12)
  533 FORMAT(2X,'STEP=',I2,'CYEAR=',I2,'AINCR',2X,12(F6.4,1X))
  595 CONTINUE
      IX=4321395
      WRITE(6,1015)
      WRITE(6,1016)
      WRITE(6,705)
  705 FORMAT(5X,60H*      ALPHA-BETA VALUES OF DAILY PANEVAPORATION
     1      *)
      WRITE(6,710)
  710 FORMAT(5X,60H*       DISTRIBUTION IN DIFFERENT MONTHS
     1      *)
      WRITE(6,1016)
      WRITE(6,1017)
      WRITE(6,720)
  720 FORMAT(///,20X,20HMONTH   ALPHA   BETA)
      DO 725 MON=1,12
  725 WRITE(6,730) MON,AL(MON),BET(MON)
  730 FORMAT(/,15X,I10,2X,F8.5,2X,F8.5)
 1015 FORMAT(1H1,4X,60H**********************************************
     1**********)
 1016 FORMAT(5X,60H*
     1      *)
 1017 FORMAT(5X,60H**********************************************
     1*******)
      READ(5,1030)CAP,GRASS
 1030 FORMAT(2F10.1)
      DO 1035 NS=1,NSOIL
 1035 READ(5,1035)(TREES(NS,NV),NV=1,NVARI)
 1036 FORMAT(1OF8.1)
C     TRSL1 : NUMBER OF TOTAL TREES OF TYPE1 ON ALL SOILS
C     TOTREE : TOTAL NUMBER OF TREES
      READ(5,13) TRSL1,TRSL2,TRSL3,TOTREE
      WRITE(6,1015)
      WRITE(6,13)'TRSL1,TRSL2,TRSL3,TOTREE
      WRITE(6,1016)
      WRITE(6,1037)
 1037 FORMAT(5X,60H*       CAPACITY-PLANT-SOIL DECISION
     1      *)
      WRITE(6,1016)
      WRITE(6,1017)
      WRITE(6,1040) CAP,GRASS
 1040 FORMAT(///,5X,'CAPACITY IN GALLONS',2X,F10.1,2X,'GRASS =',F4.1)
      CALL IPRII(NSOIL,NVARI,TREES)
      WRITE(6,1042)
 1042 FORMAT(//,10X,21H            PLANT TYPE)
      WRITE(6,1043)
 1043 FORMAT(10X,45H  1    2    3    4    5    6    7    8    9  )
      DO 1045 NS=1,NSOIL
 1045 WRITE(6,1046) NS,(TREES(NS,NV),NV=1,NVARI)
 1046 FORMAT(1X,'SOIL TYPE',I1,9F5.0)
      DO 119 J=1,20
      TREV(J)=0.0
      DO 119 I=1,12
  119 REVMON(I,J)=0.0
      DO 18 I=1,20
      ANDAYV(I)=0.0
      ANCABV(I)=0.0
      ANCANV(I)=0.0
      ANTRLV(I)=0.0
      TREV(I)=0.0
      DO 18 J=1,12
      VCABM(J,I)=0.0
      VDAYM(J,I)=0.0
      VCANP(J,I)=0.0
      VTRLM(J,I)=0.0
   18 CONTINUE
      DO 3015 I=1,366
      STORE(I)=0.0
 3015 CONTINUE
 9999 STOWN=0.0
      DO 1050 I=1,365
      PUMPGR(I)=0.0
      GRCONS(I)=0.0
      TTPEV(I)=0.0
      DUMP(I)=0.0
      EXTRCT(I)=0.0
      TTREQD(I)=0.0
      LOSTRN(I)=0.0
      EXCESS(I)=0.0
      WATER(I)=SEWAGE(I)
      AWATER(I)=0.0
      TTPUN(I)=0.0
 1050 CONTINUE
      DO 1047 NS=1,NSOIL
      DO 1047 NV=1,NVARI
      SMEST(NS,NV)=0.7*FC(NS)
 1047 CONTINUE
      DO 9994 I=1,12
 9994 SEWGMO(I)=0.0
      CALL RANDU(IX,IY,YFL)
      RINI=YFL
      IF(RINI.LE.PCYEAR(1))CYEAR=1
      IF(RINI.GT.PCYEAR(1).AND.RINI.LE.PCYEAR(2))CYEAR=2
      IF(RINI.GT.PCYEAR(2))CYEAR=3
      WRITE(6,3000) CYEAR
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 3000 FORMAT(1H0,2X,'CYEAR=',I2)
      CALL PAIGN(CYEAR,IX)
C
C     ******  CALL PAN EVAPORATION  **********
C
      DO 650 JKK=1,365
      CALL PMONTH(JKK,MONTH)
      ALPHA=AL(MONTH)
      BETA=PET(MONTH)
      CALL GAMMA(ALPHA,BETA,STAF1,GAM,IX,PE,JKK)
  650 CONTINUE
      IF(RTERN.LT.1.) GO TO 570
      IF(OUT1.LE.0.0) GO TO 4630
      DO 560 I=1,365
      WRITE(6,565)I,RAIN(I),PE(I)
  565 FORMAT(10X,'DAY=',I3,1X,'RAIN=',F7.3,'PANEVAPORATION=',2X,F4.2)
  560 CONTINUE
 4630 DUMMY=0.0
      IF(MXDSGN.LT.1) GO TO 5001
      YYEAR=25.
      AYYYR=YYEAR-DIFFYR+1.
      IRYR=AYYYR
      IYR=IRYR
      WRITE(6,1002)AYYYR
 1002 FORMAT(1H1,///,5X,'DAILY VISITATION AND SEWAGE FIGURES FOR',2X,F10.
     1)
      GO TO 5010
 5001 SKIP=3
      WRITE(6,1003)IYEAR
      YYEAR=YEAR-BASEYR
      YRFLAG=YYEAR-DIFFYR+1
      IY=-YSELG
      IRYR=IY
 5010 ANVST=AVESTYR*SLOPE*YYEAR
      ANVST=ANVST+ANVST
      AVST1(IRYR)=ANVST
      WRITE(6,1001)ANVST1(IRYR),IRYR,EPSLN
 1001 FORMAT(///,2X,'ANNUAL DAILY VISITS WITH TICKETS ARE',2X,F12.1,5X,'
     1YEAR',16,5X,'EPSLN=',F8.3)
C     FIND THE NUMBER OF WKENDS IN EACH MONTH
      DO 10 JJ=1,12
      ISAT(JJ)=0
   10 ISUN(JJ)=0
      DO 20 I=IFST,365,7
      CALL MMONTH(I,MONTH)
      ISAT(MONTH)=ISAT(MONTH)+1
   20 CONTINUE
      IFSUN=IFST+1
      DO 30 I=IFSUN,365,7
      CALL MMONTH(I,MONTH)
   30 ISUN(MONTH)=ISUN(MONTH)+1
      DO 40 MONTH=1,12
      IWKEND(MONTH)=ISAT(MONTH)+ISUN(MONTH)
   40 WKEND(MONTH)=IWKEND(MONTH)
C     GENERATE THE NUMBER OF WKDAYS IN EACH MONTH
      DO 50 MONTH=1,12
      GO TO (41,42,41,43,41,43,41,41,43,41,43,41),MONTH
   41 WKDAY(MONTH)=31.-WKEND(MONTH)
      GO TO 50
   42 WKDAY(MONTH)=28.-WKEND(MONTH)
      GO TO 50
   43 WKDAY(MONTH)=30.-WKEND(MONTH)
   50 CONTINUE
C     INITIALIZE
      DO 60 I=1,365
   60 DAYVIS(I)=-10.
C     GENERATE DAILY VISITATIONS IN WKENDS
      DO 80 I=IFST,365,7
      CALL MMONTH(I,MONTH)
      DAYVIS(I)=ANVST*AVMP(MONTH)*W2(MONTH)*(1./WKEND(MONTH))
      CABVIS(I) = CABIN(IRYR)*CAPPER*AVMP(MONTH)*W2(MONTH)*(1./WKEND(MON
     1TH))
      CABVIS(I)=10.*CABVIS(I)
      DAYVIS(I+1)=DAYVIS(I)
      CABVIS(I+1)=CABVIS(I)
   80 CONTINUE
C     GENERATE WKDAYS VISITORS
      DO 100 I=1,365
      IF(DAYVIS(I).GT.0.0) GO TO 85
      CALL MMONTH(I,MONTH)
      DAYVIS(I)=ANVST*AVMP(MONTH)*W1(MONTH)*(1./WKDAY(MONTH))
      CABVIS(I)=CABIN(IRYR)*CAPPER*AVMP(MONTH)*W1(MONTH)*(1./WKDAY(MONTH
     1))
      CABVIS(I)=10.*CABVIS(I)
   85 DUMMY=0.0
  100 CONTINUE
      DCNT=0.0
      DO 90 I=1,365
      IF(RAIN(I).GT.RNMAX) GO TO 88
      DCNT=DCNT+1.
      IF(RAIN(I).LE.0.0) GO TO 90
      FACRN=RAIN(I)/RNMAX
      CABVIS(I)=CABVIS(I)*(1.0-FACRN)
      DAYVIS(I)=DAYVIS(I)*(1.0-FACRN)
      GO TO 90
   88 DAYVIS(I)=0.0
      CABVIS(I)=0.0
   90 CONTINUE
      TVS1=0.0
      TVS2=0.0
      DO 95 I=1,365
      TVS1=TVS1+CABVIS(I)
      TVS2=TVS2+DAYVIS(I)
   95 CONTINUE
      FACCA=1.-CABIN(IYR)*CAPPER
      DIVEQ1=(FACCAB-TVS1)/DCNT
      DIVEQ2=(ANVST-TVS2)/DCNT
      DO 99 I=1,365
      IF(DAYVIS(I).LE.0.0) GO TO 96
      CABVIS(I)=CABVIS(I)+DIVEQ1
      DAYVIS(I)=DAYVIS(I)+DIVEQ2
      CAMPE(I)=CAMPER*DAYVIS(I)
      TRALOR(I)=TRLPER*DAYVIS(I)
      DAYVIS(I)=3.*(DAYVIS(I)-CAMP(I)-TRALOR(I))
      GO TO 99
   96 CAMP(I)=0.0
      TRALOR(I)=0.0
      DAYVIS(I)=0.0
      CABVIS(I)=0.0
   99 CONTINUE
      DO 104 I=1,365
      PEXCOE=PLINE*0.0189*CABIN(IYR)
      FILTR(I)=FILTR*RAIN(I)*FILCCE*PEXCOE
  104 CONTINUE
      IF(OUT6.LE.0.0) GO TO 4010
      DO 105 I=1,365
      WRITE(6,4015)I,RAIN(I),FILTR(I)
 4015 FORMAT(5X,'DAY=',I3,5X,'RAIN=',F4.2,2X,'INFILTRATION=',F12.2)
  105 CONTINUE
 4010 DUMMY=0.0
      SEWGYR(IYR)=0.0
C     CALCULATE CONSTANT SEWAGE
      CONSEW=0.0
      DO 110 I=1,ISORCE
  110 CONSEW=CONSEW+SOURCE(I)*FLOW(I)
      SMAX=0.0
      DO 120 I=1,365
      TRLMAX=TLMAX(IYR)
      IF(T-ALOS(I).LE.TRLMAX) GO TO 115
      TRALOR(I)=TRLMAX
      DAYVIS(I)=DAYVIS(I)-TRALOR(I)-TRLMAX
  115 SEWAGE(I)=CAMELO*CAMP(I)+TRLFLO*TRALOR(I)+VISFLO*DAYVIS(I)+CONSEW
     1+CABVIS(I)*CAFLO+FILTR(I)
      CALL MMONTH(I,MONTH)
      SEWGMO(MONTH)=SEWGMO(MONTH)+SEWAGE(I)
      SEWGYR(IYR)=SEWGYR(IYR)+SEWAGE(I)
      IF(SEWAGE(I).LE.SMAX) GO TO 120
      SMAX=SEWAGE(I)
      MAXDAY=I
  120 CONTINUE
      WRITE(6,4008)
 4008 FORMAT(2X,59HDAY      DAILY VISIT    CAMP   TRAILORS     CABINS
     1SEWAGE)
      DO 121 I=1,365
  121 REVOVE(I)=0.0
      DO 122 I=IFST,365,7
  122 REVOVE(I)=-10.
      DO 129 I=1,365
      IF(REVOVE(I).LT.0.0) GO TO 127
      REVOVE(I)=DAYVIS(I)*FEEMO/3.
      GO TO 128
  127 REVOVE(I)=DAYVIS(I)*FEESAT/3.
  128 TRLOVE(IYR)=TREOVE(IYR)+REVOVE(I)
      CALL MMONTH(I,MONTH)
      REVMON(MONTH,IYR)=REVMON(MONTH,IYR)+REVOVE(I)
  129 CONTINUE
      DO 130 I=1,365
      CALL MMONTH(I,MONTH)
      VCABM(MONTH,IRYR)=VCABM(MONTH,IRYR)+CABVIS(I)
      VDAYM(MONTH,IRYR)=VDAYM(MONTH,IRYR)+DAYVIS(I)
      VCAMP(MONTH,IRYR)=VCAMP(MONTH,IRYR)+CAMP(I)
      VTRLM(MONTH,IRYR)=VTRLM(MONTH,IRYR)+TRALOR(I)
      ANDAYVE(IRYR)=ANDAYVE(IRYR)+DAYVIS(I)
      ANCABVE(IRYR)=ANCABV(IRYR)+CABVIS(I)
      ANCAMVE(IRYR)=ANCAMV(IRYR)+CAMP(I)
      ANTRLVE(IRYR)=ANTRLV(IRYR)+TRALOR(I)
  130 CONTINUE
      IF(OUT5.LE.0.0) GO TO 4520
      WRITE(6,9) I,DAYVIS(I),CAMP(I),TRALOR(I),CABVIS(I),SEWAGE(I)
    9 FORMAT(2X,I3,4X,5(F10.1,1X))
 4520 DUMMY=0.0
      TREVE(IYR)=TREOVE(IYR)+CABIN(IYR)*CAFLIS+ANTRLV(IYR)*TRLFEE+ANCAMV(I
     1YR)*CAFEE
      DO 135 MONTH=1,12
      REVMON(MONTH,IYR)=REVMON(MONTH,IYR)+VCAMP(MONTH,IYR)*CAMFEE+VTRLM(
     1MONTH,IYR)*TRLFLE+(CABIN(IYR)*CAFLIS*1./12.)
  135 CONTINUE
      WRITE(6,11) SMAX,MAXDAY
   11 FORMAT(1H0,2X,'MAXIMUM SEWAGE FLOW IS',F15.5,'GALLONS ON',I4,'TH D
     1AY OF YEAR')
      IF(MXDSGN.LT.1) GO TO 5015
      GO TO 9990
 5015 DO 150 I=IFST,372,7
      IF(I.LE.365) GO TO 150
      IFST=I-365
  150 CONTINUE
      GO TO 5025
 9990 DMGO=SMAX/(10.0**6.)
C
C
C     ******** CALCULATE INSTALLATION COST FOR COLLECTION SYSTEM  ********
C
C
      DO 170 ICOLL=1,2
      COLL(ICOLL)=ACL(ICOLL)*CABIN(20)*(PCL(ICOLL)*CACL(ICOLL)*AEPS)
  170 CONTINUE
      WRITE(6,175) COLL(1)
  175 FORMAT(//,5X,' GRAVITY COLLECTION COST =$',F15.2)
      WRITE(6,177) COLL(2)
  177 FORMAT(//,5X,'PRESSURE COLLECTION COST =$',F15.2)
      CALL CONSTR(PODIN,DMGO,IYR,SEWGYR)
      CALL PCKAGE(DMGO,PAKON)
      MXDSGN=0
      IF(MXDSGN.LT.1) GO TO 9999
 5025 SKIP=10.
      DUMMY=0.0
C     ***********************************************************
C     *                                                         *
C     *    NS   = SOIL TYPE                                     *
C     *           FOR THE SPECIFIC SITE OF WHITE RIVER LAKE     *
C     *           TYPES OF SOIL CONSIDERED ARE -- MNR COMPLEX*  *
C     *                 0-13 INCH FINE SANDY LOAM, 10-70 INCH*  *
C     *                 SANDY CLAY LOAM, 2. LATON POLAR       * *
C     *                 COMPLEX, 0-7 INCH GRAVELLY SANDY LOAM*  *
C     *                 7-60 INCH VERY GRAVELLY SANDY LOAM    * *
C     *                 3. BERDA LOAM, 0-60 INCH LOAM OR CLAY*  *
C     *    CAP  = CAPACITY OF THE STORAGE                       *
C     *    TREPS(I,J)= # OF TREES OF J.TH VARITY IN I.TH SOIL*  *
C     *    PEV(I,J,K)= TOTAL POTENTIAL EVAPOTRANSPIRATION IN *  *
C     *                ITH DAY BY THE TREES OF KTH VARITY     * *
C     *                IN JTH SOIL                            * *
C     *    TPEV(I,J)=TOTAL POTENTIAL EVAPOTRANSPIRATION IN    * *
```

```
C     *                I'TH DAY IN J'TH SOIL IN GALLONS                *
C     *    TTPEV(I)=TOTAL EVAPOTRANSPIRATION IN I'TH DAY               *
C     *                                                                *
C     ******************************************************************
      DUMMY=0.0
C     ******************************************************************
C     *                                                                *
C     *    AREA(I,J)= CANOPY AREA OF I'TH TYPE OF TREES                *
C     *               IN J'TH YEAR OF GROWTH, IN SQ. FT.               *
C     *    PC(I)  = FIELD CAPACITY OF I'TH SOIL, IN INCHES             *
C     *    SM(I,J,K)= SOIL MOISTURE IN I'TH DAY, IN J'TH               *
C     *               SOIL UNDER K'TH TREE TYPE                        *
C     *    TREQ(I,J)= GALLONS OF WATER REQD. IN J'TH SOIL              *
C     *               IN I'TH DAY                                      *
C     *                TREE IN J'TH SOIL IN I'TH DAY                   *
C     *    TTREQD(I)=GALLONS OF WATER IN                               *
C     *    TTREQ0(I)=GALLONS OF WATER REQD. IN I'TH DAY                *
C     *    EXCESS(I)    = GALLONS OF EFFLUENT IN I'TH DAY              *
C     *                   MINUS TTREQD(I)                              *
C     *    STORE(I)     = GALLONS OF EFFLUENT STORED IN STAB.          *
C     *                   POND IN I'TH DAY                             *
C     *    AVSTOR       = STORAGE AVAILABLE = CAP-STORE(I)             *
C     *                                                                *
C     ******************************************************************
      IF(OUT2.LE.0.0) GO TO 4017
      WRITE(6,1015)
      WRITE(6,1016)
      WRITE(6,4016)
 4016 FORMAT(5X,60H  SIMULATED  MOISTURE  BALANCE  INFORMATIONS
     1     =)
      WRITE(6,1016)
      WRITE(6,1017)
 4017 DUMMY=0.0
      DO 2000 I=1,365
C
C     IRRIGATE THE GRASS
C
      IF(GRASS.LE.0.0) GO TO 4019
      CALL MMONTH(I,MONTH)
      GRCONS(I)=PE(I)*GKCOEF(MONTH)*.8
      GRCONS(I)=GRCONS(I)-RAIN(I)
      IF(GRCONS(I).GT.0.0) GO TO 4005
      GRCONS(I)=0.0
      GO TO 4019
 4005 GRCONS(I)=GRCONS(I)*GRASS*27154./EFFIRR(MIRRI)
      IF(GRCONS(I).GT.WATER(I)) GO TO 4022
      WATER(I)=WATER(I)-GRCONS(I)
      GO TO 4019
 4022 SHORT=GRCONS(I)-WATER(I)
      IF(SHORT.GT.STORE(I)) GO TO 4027
      STORE(I)=STORE(I)-SHORT
      WATER(I)=1.
      GO TO 4019
 4027 DUMMY=(-SHORT-STORE(I)
      STORE(I)=0.0
      WATER(I)=1.
 4019 DUMMY=0.0
      TTPEV(I)=0.0
      DO 1070 NNSOIL=1,NSOIL
      TPEV(I,NNSOIL)=0.0
      DO 1060 NV=1,NVARI
      PEV(I,NNSOIL,NV)=3.1416*(RO(NV,IYR)**2.)*PE(I)*.436*TREES(NNSOIL,N
     1V)
      IF(OUT2.LE.0.0) GO TO 4026
      WRITE(6,4020)
 4020 FORMAT(10X,'*******  DAILY POTENTIAL EVAPOTRANSPIRATION  *******')
      WRITE(6,4025) I,NNSOIL,NV,PEV(I,NNSOIL,NV)
 4025 FORMAT(10X,'DAY',I4,'SOIL PLOT',I2,'PLANT SPECIES',I5,'PEV IN GALLO
     1NS=',F14.3)
 4026 DUMMY=0.0
 1060 TPEV(I,NNSOIL)=TPEV(I,NNSOIL)+PEV(I,NNSOIL,NV)
      TTPEV(I)=TTPEV(I)+TPEV(I,NNSOIL)
      IF(OUT2.LE.0.0) GO TO 1070
      WRITE(6,4031) I,NNSOIL,TPEV(I,NNSOIL)
 4031 FORMAT(////,5X,'TOTAL DAILY POTENTIAL EVAPOTRANSPIRATION  IN DAY',I
     1A' IN SOIL',I3,'IS',F14.3)
 1070 CONTINUE
      IF(OUT2.LE.0.0) GO TO 4031
      WRITE(6,4033) I,TTPEV(I)
 4033 FORMAT(///,5X,'TOTAL POTENTIAL EVAPOTRANSPIRATION IN DAY ',I4,'IS
     1IN GALLONS',F14.3)
 4031 DUMMY=0.0
      TTREQ(I)=0.0
      IF(OUT2.LE.0.0) GO TO 4042
      WRITE(6,4040)
 4040 FORMAT(////,50H*****  DAILY IRRIGATION REQD  ********************)
 4042 DUMMY=0.0
      DO 1120 NNSOIL=1,NSOIL
      TREQ(I,NNSOIL)=0.0
      DO 1100 NV=1,NVARI
      IF(TREES(NNSOIL,NV).LE.0.0) GO TO 1100
      CANOPY(NV,IYR)=3.1416*(RO(NV,IYR)**2.)
      IF(I.EQ.1) GO TO 1080
      REQD(I,NNSOIL,NV)=.6233*FC(NNSOIL)*CANOPY(NV,IYR)*TREES(NNSOIL,NV)
     1+PEV(I,NNSOIL,NV)-.6233*RAIN(I)*CANOPY(NV,IYR)*TREES(NNSOIL,NV)-SM
     1(I-1,NNSOIL,NV)*.6233*CANOPY(NV,IYR)*TREES(NNSOIL,NV)
      REQD(I,NNSOIL,NV)=REQD(I,NNSOIL,NV)/EFFIRR(MIRRI)
      GO TO 1092
 1080 IF(IYR.NE.1) GO TO 1082
      REQD(I,NNSOIL,NV)=.6233*FC(NNSOIL)*CANOPY(NV,IYR)*TREES(NNSOIL,NV)
     1+PEV(I,NNSOIL,NV)-.6233*RAIN(I)*CANOPY(NV,IYR)*TREES(NNSOIL,NV)-SM
     1(I,NNSOIL,NV)*.6233*CANOPY(NV,IYR)*TREES(NNSOIL,NV)
      REQD(I,NNSOIL,NV)=REQD(I,NNSOIL,NV)/EFFIRR(MIRRI)
      GO TO 1092
 1082 REQD(I,NNSOIL,NV)=.6233*FC(NNSOIL)*CANOPY(NV,IYR)*TREES(NNSOIL,NV)
     1+PEV(I,NNSOIL,NV)-.6233*RAIN(I)*CANOPY(NV,IYR)*TREES(NNSOIL,NV)-SM
     1(I,NNSOIL,NV)*.6233*CANOPY(NV,IYR)*TREES(NNSOIL,NV)
      REQD(I,NNSOIL,NV)=REQD(I,NNSOIL,NV)/EFFIRR(MIRRI)
 1092 DUMMY=0.0
      IF(OUT2.LE.0.0) GO TO 4047
      WRITE(6,4045) I,NNSOIL,NV,REQD(I,NNSOIL,NV)
 4045 FORMAT(5X,'IRRIGETION REQD. IN DAY',I4,' IN SOIL',I2,' IN PLANTS',
     113,'IN GALLONS=',F14.3)
 4047 DUMMY=0.0
      TREQ(I,NNSOIL)=TREQ(I,NNSOIL)+REQD(I,NNSOIL,NV)
 1100 CONTINUE
      IF(OUT2.LE.0.0) GO TO 4049
      WRITE(6,4050) I,NNSOIL,TREQ(I,NNSOIL)
 4050 FORMAT(///,5X,' TOTAL IRRIGATION REQD IN DAY',I4,'IN SOIL',I2,' IS
     1IN GALLONS',F14.3)
 4049 DUMMY=0.0
      TT=TTREQD(I)+TTREQ0(I,NNSOIL)
 1120 CONTINUE
      IF(OUT2.LE.0.0) GO TO 4058
      WRITE(6,4055) I,TTREQD(I)
 4055 FORMAT(5X,'TOTAL IRRIGATION REQD IN DAY',I4,'IS (IN GALLONS)',F14.
     13)
 4058 DUMMY=0.0
C
C     ******  FIND TOTAL AREA  ***************
C
      AAREA=0.0
      DO 1130 II=1,NSOIL
      AREA(II)=0.0
      DO 1130 J=1,NVARI
 1130 AREA(II)=AREA(II)+(3.4116*(RO(J,IYR)**2.)*TREES(II,J))
      IF(OUT2.LE.0.0) GO TO 4064
      WRITE(6,4060) II,AREA(II)
 4060 FORMAT(5X,'EFFECTIVE CANOPY AREA ON SOIL',I2,' IS IN (SQ. FT)',F14
     1.3)
 4064 DUMMY=0.0
      AAREA=AAREA+AREA(II)
 1140 CONTINUE
      IF(OUT2.LE.0.0) GO TO 4067
      WRITE(6,4065) AAREA
 4065 FORMAT(////,5X,'TOTAL CANOPY AREA (IN SQ. FT. )',F14.3)
 4067 DUMMY=0.0
      IF(TTREQD(I).GT.0.0) GO TO 1150
C
C     ********  IRRIGATION NOT REQUIRED  ********
C
      LOSTWN(I)=(TTREQD(I)*(-1.6043))/AAREA
      EXCESS(I)=WATER(I)
      IF(OUT2.LE.0.0) GO TO 4072
      WRITE(6,4070) I,EXCESS(I),LOSTWN(I)
 4070 FORMAT(////,5X,'IRRIGATION NOT REQD IN DAY',I4,'  EXCESS(I)=',F14.3
     1,'LOSTWN(I)=',F14.8)
 4072 DUMMY=0.0
      GO TO 1160
C
C     **********  IRRIGATION REQUIRED  ************
C
 1150 IF(TTREQD(I).GT.WATER(I)) GO TO 1190
      EXCESS(I)=WATER(I)-TTREQD(I)
C
C     ******  IRRIGATION REQD. BUT EFFLUENT EXCESS  **********
C
      IF(OUT2.LE.0.0) GO TO 4077
      WRITE(6,4075) I,EXCESS(I),WATER(I)
 4075 FORMAT(2X,///,'DAY=',I3,5X,'EXCESS GALLONS=',F10.1,5X,'EFFLUENT',2X
     1,F10.1)
 4077 DUMMY=0.0
 1160 IF(STORE(I).EQ.CAP) GO TO 1180
      AVSTOR= CAP-STORE(I)
      IF(OUT2.LE.0.0) GO TO 4088
      WRITE(6,4081) I,STORE(I),CAP,AVSTOR
 4081 FORMAT(///,2X,'DAY',I3,5X,'STORE=',2X,F10.1,2X,'CAP=',F10.1,2X,'AVS
     1STOR=',F10.1)
      WRITE(6,4336) I,DUMP(I),EXCESS(I)
 4086 FORMAT(/,2X,'DAY=',I3,5X,'DUMP=',F10.1,5X,'EXCESS=',F10.1)
 4088 DUMMY=0.0
      IF(AVSTOR.LE.EXCESS(I)) GO TO 1170
      STORE(I+1)=STORE(I)+EXCESS(I)
      DO 1169 NS=1,NSOIL
      DO 1169 NV=1,NVARI
 1169 SM(I,NS,NV)=FC(NS)
      GO TO 1730
 1170 DUMP(I)=EXCESS(I)-AVSTOR
      GO TO 1185
 1180 DUMP(I)=EXCESS(I)
      IF(OUT2.LE.0.0) GO TO 4090
      WRITE(6,4087) DUMP(I),I
 4087 FORMAT(//,2X,'NO STORAGE DUMP=EXCESS   DUMP=',F10.1,2X,'DAY=',I3)
 4090 DUMMY=0.0
 1185 STORE(I+1)=CAP
      IF(OUT2.LE.0.0) GO TO 4193
      WRITE(6,4391) DUMP(I),I
 4391 FORMAT(//,2X,'PARTIAL STORAGE.  DUMP=',F15.2,5X,'DAY=',I3)
 4193 DUMMY=0.0
      DO 1187 NS=1,NSOIL
      DO 1187 NV=1,NVARI
 1187 SM(I,NS,NV)=FC(NS)
      GO TO 1730
C
C
C     *********  EFFLUENT DEFICIT. EXTRACT FROM STORE  **********
C
C
 1190 EXTRCT(I)=TTREQD(I)-WATER(I)
      IF(OUT2.LE.0.0) GO TO 4094
      WRITE(6,4390) EXTRCT(I),TTREQD(I),WATER(I),I
 4094 FORMAT(//,2X,'EFFL SHORT EXTRCT=',F10.1,2X,'TTREQD=',F10.1,2X,'WAT
     1ER=',F10.1,2X,'DAY',I3)
 4094 DUMMY=0.0
      IF(EXTRCT(I).GT.STORE(I)) GO TO 1210
C
C
C     ****   ENOUGH EFFLUENT AVAILABLE FROM STORE  **********
C
C
      IF(OUT2.LE.0.0) GO TO 4097
      WRITE(6,4091) I
 4091 FORMAT(//,2X,'EXTRCT NOT EXCEEDS STORE  I=',I3)
 4097 DUMMY=0.0
      STORE(I+1)=STORE(I)-EXTRCT(I)
      IF(OUT2.LE.0.0) GO TO 4099
      I9=I+1
      WRITE(6,4093) STORE(I9),STORE(I),EXTRCT(I)
 4093 FORMAT(//,2X,'STORE(I+1 =',F10.1,2X,'STORE=',F10.1,2X,'EXTRCT=',F10
     1.1)
 4099 DUMMY=0.0
      DO 1200 NNSOIL=1,NSOIL
```

```
      DO 1200 NVAP=1,NVARI
 1203 SM(I,NSOIL,NVAR)=PC(NSOIL)
      GO TO 1700
 1210 STORE(I+1)=0.0
C
C
C     ***   TOTAL EFFLUENT IS NOT SUFFICIENT TO MEET  TOTAL DEMAND ***
C
C
      AWATER(I)=WATER(I)+STORE(I)
      IF(IOUT2.LE.0.0) GO TO 4101
      WRITE(6,4095) I,AWATER(I),WATER(I),EXTRCT(I)
 4095 FORMAT(//,2X,'DAY=',I3,2X,'AWATER=',F10.1,2X,'WATER=',F10.1,2X,'EX
     1TRCT=',F10.1)
 4101 DUMMY=0.0
      FACTOR=SMIN
      ITER=1
      RAIN=RAIN(I)
      PPE=PPE(I)
 1503 CALL SMSOL(SUM2,NSOIL,NVARI,IYR,I,RRAIN,PPE,CONVRT,FACTOR)
      IF(ITER.EQ.1.AND.SUM2.GT.AWATER(I)) GO TO 1549
      IF(SUM2.GT.AWATER(I))GO TO 1505
      FACTOR=FACTOR+0.1
      ITER=ITER+1
      GO TO 1503
 1505 FACTOR=FACTOR-0.09
 1507 CALL SMSOL(SUM2,NSOIL,NVARI,IYR,I,RRAIN,PPE,CONVRT,FACTOR)
      IF(SUM2.GT.AWATER(I)) GO TO 1509
      FACTOR=FACTOR+0.01)
      GO TO 1507
 1509 FACTOR=FACTOR-0.0090
 1514 CALL SMSOL(SUM2,NSOIL,NVARI,IYR,I,RRAIN,PPE,CONVRT,FACTOR)
      IF(SUM2.GT.AWATER(I)) GO TO 1517
      FACTOR=FACTOR+0.001
      GO TO 1514
 1517 DUMMY=0.0
      IF(IOUT2.LE.0.0) GO TO 4105
      WRITE(6,4098) I,FACTOR,SUM2,AWATER(I)
 4098 FORMAT(//,2X,'DAY=',I3,2X,'EFFLUENT DEFICIT, BUT LAKE WATER NOT NE
     1CESSARY   FACTOR=',F5.3,2X,'SUM2=',F15.2,2X,'AWTER=',F15.3)
 4105 DUMMY=0.0
      DO 1521 NS=1,NSOIL
      DO 1520 NV=1,NVARI
      IF(TREES(NS,NV).LE.0.0) GO TO 1520
      IF(FLAG(NS,NV).GT.5.) GO TO 1525
      SM(I,NS,NV)=FACTOR*PC(NS)
      IF(IOUT4.LE.0.0) GO TO 4109
      WRITE(6,4096) I,NS,NV,FACTOR,PC(NS),SM(I,NS,NV)
 4096 FORMAT(//,2X,'DAY=',I3,2X,'NS=',I3,2X,'NV=',I3,2X,'FACTOR=',F5.3,2
     1X,'PC(NS)=',F5.3,2X,'SM=',F15.3)
 4109 DUMMY=0.0
      GO TO 1530
 1525 DUMMY=0.0
      A=1./WHC(NS)
      B=(PC(NS)-WHC(NS))/WHC(NS)
      IF(IYR.EQ.1.AND.I.EQ.1) GO TO 1523
      IF(IYR.GT.1.AND.I.EQ.1) GO TO 1526
      SM(I,NS,NV)=SM(I-1,NS,NV)*.6233+TREES(NS,NV)*CANOPY(NV,IYR)*RAIN(I
     1)*.6233*TREES(NS,NV)*CANOPY(NV,IYR)-(A*SM(I-1,NS,NV)-B)*.7*PE(I)*T
     1REES(NS,NV)*CANOPY(NV,IYR)*.6233
      SM(I,NS,NV)=SM(I,NS,NV)/(1.6233*CANOPY(NV,IYR)*TREES(NS,NV))
      IF(IOUT4.LE.0.0) GO TO 4115
      WRITE(6,4317)I,NS,NV,A,B,SM(I,NS,NV)
 4317 FORMAT(//,2X,'DAY=',I3,2X,'NS=',I3,2X,'NV=',I3,2X,'A=',F10.3,2X,'B
     1=',F10.3,'SM=',F10.4)
 4115 DUMMY=0.0
      GO TO 1530
 1523 DUMMY=0.0
      SM(I,NS,NV)= SMFST(NS,NV)*.6233*TREES(NS,NV)*CANOPY(NV,IYR)+RAIN(I
     1)*.6233*TREES(NS,NV)*CANOPY(NV,IYR)-(A* SMFST(NS,NV)-B)*.7*PE(I)*T
     1REES(NS,NV)*CANOPY(NV,IYR)*.6233
      SM(I,NS,NV)=SM(I,NS,NV)/(1.6233*CANOPY(NV,IYR)*TREES(NS,NV))
      IF(IOUT4.LE.0.0) GO TO 4117
      WRITE(6,4317)I,NS,NV,A,B,SM(I,NS,NV)
 4117 DUMMY=0.0
      GO TO 1530
 1526 DUMMY=0.0
      SM(I,NS,NV)= SMLST(NS,NV)*.6233*TREES(NS,NV)*CANOPY(NV,IYR)+RAIN(I
     1)*.6233*TREES(NS,NV)*CANOPY(NV,IYR)-(A* SMLST(NS,NV)-B)*.7*PE(I)*T
     1REES(NS,NV)*CANOPY(NV,IYR)*.6233
      SM(I,NS,NV)=SM(I,NS,NV)/(1.6233*CANOPY(NV,IYR)*TREES(NS,NV))
      IF(IOUT4.LE.0.0) GO TO 4119
      WRITE(6,4317)I,NS,NV,A,B,SM(I,NS,NV)
 4119 DUMMY=0.0
 1530 DUMMY=0.0
 1523 CONTINUE
      GO TO 1700
 1540 DUMMY=0.0
      DO 1545 NS=1,NSOIL
      DO 1545 NV=1,NVARI
      PUMP(I,NS,NV)=0.0
 1545 CONTINUE
      TTPUM(I)=0.0
      DO 1580 J=1,NSOIL
      TPUMP(I,J)=0.0
      DO 1570 K=1,NVARI
      IF(TREES(J,K).LE.0.0) GO TO 1570
      CONVRT=0.6233*CANOPY(K,IYR)*TREES(J,K)
      FAC2=1./WHC(NS)
      FAC1=(PC(NS)-WHC(NS))/WHC(NS)
      ACTEVP=(FAC2+FACTOR*PC(J)-FAC1)*0.7*PE(I)*CONVRT
      IF(I.EQ.1.AND.IYR.EQ.1) GO TO 1660
      IF(I.EQ.1.AND.IYR.GT.1) GO TO 1670
      PUMP(I,J,K)=SMMIN*PC(J)*CONVRT-SM(I-1,J,K)*CONVRT-RAIN(I)*CONVRT+
     1ACTEV
      PUMP(I,J,K)= PUMP(I,J,K)/EFFIRR(MIRRI)
      GO TO 1680
 1660 PUMP(I,J,K)=SMMIN*PC(J)*CONVRT-SMFST(J,K)*CONVRT-RAIN(I)*CONVRT+AC
     1TEV
      PUMP(I,J,K)= PUMP(I,J,K)/EFFIRR(MIRRI)
      GO TO 1680
 1670 PUMP(I,J,K)=SMMIN*PC(J)*CONVRT-SMLST(J,K)*CONVRT-RAIN(I)*CONVRT+AC
     1TEV
      PUMP(I,J,K)= PUMP(I,J,K)/EFFIRR(MIRRI)
 1680 DUMMY=0.0
      SM(I,J,K)=SMMIN*PC(J)
      IF(IOUT2.LE.0.0) GO TO 4125
      WRITE(6,1689)I,J,K,PUMP(I,J,K),SM(I,J,K)
 1689 FORMAT(//,2X,'DAY=',I3,2X,'NS=',I3,2X,'NV=',I3,2X,'PUMP=',F10.1,2X
     1,'SM=',F5.3)
 4125 DUMMY=0.0
      TPUMP(I,J)=TPUMP(I,J)+PUMP(I,J,K)
 1570 CONTINUE
      IF(IOUT2.LE.0.0) GO TO 4130
      WRITE(6,1693) I,J,TPUMP(I,J)
 1693 FORMAT(//,2X,'DAY=',I3,2X,'SOIL=',I3,2X,'TPUMP=',F10.1)
 4130 DUMMY=0.0
      TTPUM(I)=TPUMP(I,J)+TTPUM(I)+PUMPGP(I)-AWATER(I)*EFFIRR(MIRRI)
      IF(IOUT2.LE.0.0) GO TO 4135
      WRITE(6,1697)I,TTPUM(I)
 1697 FORMAT(//,2X,'DAY=',I3,2X,'TTPUM=',F10.1)
 4135 DUMMY=0.0
 1580 CONTINUE
 1700 DUMM=0.0
      IF(I.NE.365) GO TO 2000
      CALL COUNT(IYR)
C
C     FIND OPERATION COST FOR TREATMENT PLANT
C
      OPM=0.3
      CALL CONST(ROOIN,OMGD,IYR,SENGYR)
C
C        MIRRI=1  :  SUBMATIC  :  AUTO
C        MIRRI=2  :  SPRINKLER :  AUTO
C        CALCULATE CHLORINATION COST
C
      IF(MIRRI.LE.1) GO TO 1720
      CL2ACT(IYR)=SENGYR(IYR)*ACHL(2)*PCL2*10.32
      CL2OTH(IYR)=SENGYR(IYR)*BCHL(2)*PCL2*10.32
      GO TO 1740
 1720 CL2ACT(IYR)=SENGYR(IYR)*ACHL(1)*PCL2*10.32
      CL2ACT(IYR)=(TD1(IYR)*(ACHL(2)-ACHL(1)))*PCL2**4.546/453590.)+CL2ACT
     1(IYR)
      CL2OTH(IYR)=SENGYR(IYR)*BCHL(2)*PCL2*10.32
      CL2OTH(IYR)=(TD1(IYR)*(BCHL(2)-BCHL(1)))*PCL2**4.546/453590.)+CL2OTH
     1(IYR)
C     CALCULATE EMMITER REPLACEMENT COST
      EMITER=0.0
      DO 1730 NS=1,NSOIL
      DO 1730 NV=1,NVARI
      IF(TREES(NS,NV).EQ.0.0) GO TO 1730
      EMITER=EMITER+2.*TREES(NS,NV)
 1730 CONTINUE
      EMITER=EMITER*(GRASS*4840.)
      CEMGR(IYR)=(CLOSPCT/100.)*EMITER*COSTEM
      CSTFLT(IYR)=CLNHR*HRPATE*365.
      PCWIRR(IYR)=SENGYR(IYR)*(10.0**6.)+TPI(IYR)-TDI(IYR)
      PCWIRR(IYR)=PCWIRR(IYR)*.746*2.*KWH/2400.
      PCWDMP(IYR)=TDI(IYR)*.746*2.*KWH/2400.
      PCWPMP(IYR)=TPI(IYR)*.746*2.*KWH/2400.
C     PCWPMP(IYR)= POWER COST FOR PUMPING LAKE WATER AND COST OF WATER
      PCWPMP(IYR)=PCWPMP(IYR)+(0.2*TPI(IYR)/1000.)
      FMEDIA(IYR)=CART*2.*CASTPR
      FMEDIA(IYR)=FMEDIA(IYR)+SILICA*SILIPR*2.
      TIRRIC(IYR,1)=CLOG(IYR)+CSTFLT(IYR)+PCWIRR(IYR)+FMEDIA(IYR)
      TIRRIC(IYR,2)=TIRRIC(IYR,1)
      GO TO 1375
 1740 DUMMY=0.0
C
C        OPERATION COST FOR AUTOMATIC SPRINKLER
C
      PCWIRR(IYR)=SENGYR(IYR)*(10.0**6.)+TPI(IYR)-TDI(IYR)
      PCWIRR(IYR)=PCWIRR(IYR)*.746*4.*KWH/2400.
      PCWDMP(IYR)=TDI(IYR)*.746*2.*KWH/2400.
      PCWPMP(IYR)=TPI(IYR)*.746*2.*KWH/2400.
      PCWPMP(IYR)=PCWPMP(IYR)+(0.2*TPI(IYR)/1000.)
      TIRRIC(IYR,2)=PCWIRR(IYR)
      TIRRIC(IYR,1)=PCWIRR(IYR)
C        TIRRIC(IYR,K)   : K=1  :  TOTAL IRRIGATION OP. COST.
C                                  ACT. SLUDGE
C                        : I=2  FOR OTHER TREATMENT PROCESSES
 1375 DUMMY=0.0
      SLUDGE(IYR)=SLUCST*SENGYR(IYR)*0.639
C        CALCULATE OPERATION COST FOR COLLECTION SYSTEM
C        NCOLL=1  :  GRAVITY COLLECTION
C        NCOLL=2  :  PRESSURE COLLECTION
      IF(NCOLL.EQ.1) GO TO 3335
C     MAINTENANCE COSTS IN GRINDERS
C     GRINDER REPAIR + OIL ETC.
      GRICST(IYR)=.05*GRIRP*GRIND(IYR)
      GRICST(IYR)=GRICST(IYR)+GGRM*GRIND(IYR)
C     ADD MAINTENANCE AND REPLACEMENT COST OF BOOSTERS
      BOOST=100.+(0.5*AEPS)
      GRICST(IYR)=GRICST(IYR)+BOOST
C     POWER COST FOR GRINDERS
      POWCOL(IYR)=SENGYR(IYR)*1000000.*1.5*.746*KWH/600.
C     ADD POWER COSTS FOR BOOSTERS
      POWCOL(IYR)=POWCOL(IYR)*(.0125*AEPS+2.6)
      GO TO 3340
 3335 POWCOL(IYR)=SENGYR(IYR)*1000000.*8.*.746*KWH/2400.
      POWCOL(IYR)=POWCOL(IYR)*1.73
C     MAINTENANCE COSTS OF THE LIFT STATIONS + THAT ON PIPES SUCH AS
C     FLUSHING ETC.
      GRICST(IYR)=14.*20.+(50.+0.625*AEPS)
 3340 DUMMY=0.0
      WRITE(6,1751)
 1751 FORMAT(1H1,6(/),5X,'ANNUAL COST ELEMENTS',I5)
      WRITE(6,1752)MIRRI,NCOLL
 1752 FORMAT(//,2X,'IRRIGATION BY METHOD',I4,5X,'COLLECTION BY METHOD',I
     14)
      IF(MIRRI.EQ.1)GO TO 1760
      WRITE(6,1753)CL2ACT(IYR)
 1753 FORMAT(//,5X,'CHLORINATION(ACTIVATED SLUDGE)     =  $',2X,F15.1)
      WRITE(6,1754)CL2TH(IYR)
 1754 FORMAT(/,5X,'CHLORINATION(OTHER TREATMENTS )     =  $',2X,F15.1)
      GO TO 1770
 1760 WRITE(6,1753)CL2ACT(IYR)
      WRITE(6,1754)CL2TH(IYR)
      WRITE(6,1761)CLOG(IYR)
 1761 FORMAT(/,5X,'MAINTENANCE COST FOR EMITERS     =  $',2X,F15.1)
      WRITE(6,1762)CSTFLT(IYR)
 1762 FORMAT(/,5X,'COST FOR CLEANING THE SCREENS    =  $',2X,F15.1)
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```
      WRITE(6,1763) FMEDIA(IYR)
 1763 FORMAT(/,5X,'COST FOR FILTERING MEDIA          :  =  $',2X,F15.1)
 1770 WRITE(6,1755) POWIRR(IYR)
 1755 FORMAT(/,5X,'PUMPING COST FOR IRRIGATION    :  =  $',2X,F15.1)
      WRITE(6,1756)POWPMP(IYR)
 1756 FORMAT(/,5X,'PUMPING COST FOR EXCESS EFFLUENT:  =  $',2X,F15.1)
      WRITE(6,1757)POWPMP(IYR)
 1757 FORMAT(/,5X,'COST TO PUMP WATER FROM LAKE    :  =  $',2X,F15.1)
      WRITE(6,1758)TIRRIC(IYR,NIRR1)
 1758 FORMAT(/,5X,'TOTAL OPN COST FOR IRRIGATION   :  =  $',2X,F15.1)
      WRITE(6,1774)SLUDGE(IYR)
 1774  FORMAT(/,5X,'SLUDGE HANDLING COST            :  =   $',2X,F15.1)
      WRITE(6,1771)POWCOL(IYR)
 1771 FORMAT(/,5X,'POWER COST FOR COLLECTION SYSTEM   =  $',2X,F15.1)
      IF(NCOLL.EQ.1)GO TO 1775
      WRITE(6,1772) GRICST(IYR)
 1772 FORMAT(/,5X,'MAINTENANCE ON GRINDERS            =  $',2X,F15.1)
 1775 DUMMY=0.0
      DO 1750 NS=1,NSOIL
      DO 1750 NV=1,NVARI
      SMLST(NS,NV)=S*(365,NS,NV)
 1750 CONTINUE
 2000 CONTINUE
  570 DUM=0.0
      YEAR=YEAR+1.
      STORE(1)=STORE(366)
      IF(IYR.GT.1) GO TO 2050
C     FIXTR= FIXED COSTS ON TREES
      FIXTR=TREES*TTREE*TRUNK(1,1)
      REPLTR(1)=0.36*TTREE*TRUNK(1,1)*TREES*1.3
      GO TO 2060
 2050 IF(IYR.NE.2) GO TO 2055
      REPLTR(2)=TREES*TASL1*.24*TRUNK(1,2)*1.3
      REPLTR(2)=REPLTR(2)+(TREES*TASL2*.24*TRUNK(2,2)*1.3)
      REPLTR(2)=REPLTR(2)+(TREES*TASL3*.24*TRUNK(3,2)*1.3)
      GO TO 2060
 2055 IF(IYR.NE.3) GO TO  2065
      REPLTR(3)=TREES*TASL1*.12*TRUNK(1,3)*1.3
      REPLTR(3)=REPLTR(3)+(TREES*TASL2*.12*TRUNK(2,3)*1.3)
      REPLTR(3)=REPLTR(3)+(TREES*TASL3*.12*TRUNK(3,3)*1.3)
      GO TO 2060
 2065 REPLTR(IYR)=0.0
 2060 DUMMY=0.0
C     ADD COSTS OF PRUNNING AND DUSTING = .04336/TREE/FT OF CANOPY DIA
      REPLTR(IYR)=REPLTR(IYR)+0.083*(PRC(1,IYR)*(TREES(1,1)+TREES(2,1)+TR
     1EES(3,1)))
      REPLTR(IYR)=REPLTR(IYR)+0.083*(PRC(2,IYR)*(TREES(1,2)+TREES(2,2)+TR
     1EES(3,2)))
      REPLTR(IYR)=REPLTR(IYR)+0.083*(PRC(3,IYR)*(TREES(1,3)+TREES(2,3)+TR
     1EES(3,3)))
      REPLTR(IYR)=REPLTR(IYR)+GRASS*6.
      IF(IYR.NE.1) GO TO 2070
      WRITE(6,2341)FIXTR
 2080 FORMAT(///,5X,'COSTS FOR PLANTING THE TREES =$',F12.0)
 2070 WRITE(6,2085)REPLTR(IYR),IYR
 2085 FORMAT(///,5X,'MAINTENANCE ON TREES, GRASS ALONG WITH REPLACEMENT
     1 OF DEAD TREES = $',F12.0,2X,'IN YEAR ',I3)
      IF(YEAR.LE.1994.) GO TO 9999

      DO 2090 IIK=1,20
 2090 POWCOL(IIK)=POWCOL(IIK)+GRICST(IIK)
      CALL TABLE(MIRRI,NCOLL,TRCONS,COLL,CONSIR,OPNTPC,POWCOL,TIRRIC,SLU
     1DGE,CL2PTN,CL2ACT,POWPMP,POWPMP,PNTRST,TREV,FIXTR,REPLTR)
      CALL EXIT
      END



                              AMOUNT

      SUBROUTINE AMOUNT(MONTH,CYEAR,I,IX)
      INTEGER CYEAR
      COMMON/BLOCK6/RAIN(365)
      COMMON/BLOCK1/RDAY(3),DD(3,12),RANGE(10,3,12),
     1START(10,3,12),DW(3,3,12),AINCRE(10,3,12)
C     ********************************************************
C     *                                                      *
C     *   THIS SUBROUTINE GENERATES THE DAILY AMOUNT         *
C     *   OF RAIN                                            *
C     *                                                      *
C     ********************************************************
      CALL RANDU(IX,IY,YFL)
      RINI=YFL
      FFLAG=1.0
      DO 10 J=1,10
      IF(FFLAG.GT.0.0) GO TO 10
      IF(RINI.LE.RANGE(J,CYEAR,MONTH)) GO TO 5
      GO TO 10
    5 JK=J
      FFLAG=10.
   10 CONTINUE
      CALL RANDU(IX,IY,YFL)
      RINI=YFL
      T=.1
      AJ=START(JK,CYEAR,MONTH)
   15 IF(RINI.LE.T) GO TO 17
      AJ=AJ+AINCRE(JK,CYEAR,MONTH)
      T=T+.1
      GO TO 15
   17 RAIN(I)=AJ
      RETURN
      END
```

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      SUBROUTINE CONSTR(BCOIN,CMGD,IYR,SEWGYR)
      DIMENSION SEWGYR(20)
      DIMENSION PAOIN(2)
      COMMON/BLOCK2/A0(5),A1(5),B2(5),T(5),RENS(5),CX1(5),CX2(5),C11(5),
     1C12(5),C22(5),WPC(20),YY(20),YLIMIT(5),XLIMIT(5),CNE(5),COEF(20),
     1AP(20),COST(20),OCOST(20), CMIC=(6),CONSM(6),POMICH(6),COEF(20),
     1OP(20),RPC,ICITY,JYEAR,AVNAT,AENW,CPNTPC(7,20),TPCONS(7),OPN
      COMMON/BLOCK1/OUT11
      IF(OPN.LT.10.0) GO TO 9000
C*************************************************************
C*                                                           *
C*    THE COST ESTIMATE EQUATIONS USED IN THIS SUBPROGRAM FOR PRIMARY,  *
C*    STABILIZATION PONDS, STD. TRICKLING, HIGH RATE TRICKLING, AND    *
C*    ACTIVATED SLUDGE PLANTS ARE VALIED FOR FOLLOWING RANGES          *
C*    TYPE OF PLANT                  VALISC PREDICTION RANGE(DESIGN PE) *
C*    PRIMARY                        3.0-24000                         *
C*    WASTE STABILIZATION POND       250-55000                         *
C*    STD. TRICKLING FILTER PLANT    215-80.0 ?                        *
C*    HIGH RATE TRICKLING FILTER PLANT 600-125000                      *
C*    ACTIVATED SLUDGE PLANT         333-53.0.00                       *
C*    REF- SHAH AND REID-WPCF JOURNAL-VOL-42-NO-5-MAY'70               *
C*                                                           *
C*************************************************************
C*************************************************************
C*                                                           *
C*    PUNCH THE SERIAL NUMBER OF THE NEAREST CITY FROM THE FOLLOWING    *
C*    TABLE FOR ICITY                                        *
C*    ATLANTA=1,BALTIMORE=2,BIRMINGHAM=3,BOSTON=4,CHICAGO=5,           *
C*    CINCINNATI=6,CLEVELAND=7,DALLAS=8,DENVER=9,DETROIT=10,KANSAS     *
C*    CITY=11,LA=12,MINNEAPOLIS=13,NEWORLEANS=14,NEWYORK=15,PHILADEL-  *
C*    PHIA=16,PITTSBURGH=17,ST.LOUIS=18,SANFRACISCO=19,SEATTLE=20      *
C*    JYEAR IS THE YEAR AT WHICH THE COST OF CONSTRUCTION IS NEEDED    *
C*    9=POP PER CAPITA PER DAY. ASSUMED TO BE .17 LB/CAPITA/DAY        *
C*                                                           *
C*************************************************************
      PE=8.33*CMGD*POPIN/RPC
C*************************************************************
C*                                                           *
C*    WPC(I)=WPC-STP INDEXES FOR 20 CITIES AT JYEAR          *
C*                                                           *
C*************************************************************
      DO 20 I=1,5
      Y=A0(I)+B1(I)*ALOG(PE)+B2(I)*ALOG(CMGD)
      IF(I.NE.2) GO TO 10
      Y=1./Y
   10 IF(I.NE.1) GO TO 14
C     COST ESTIMATE FOR PRIMARY TREATMENT PLANT
      YY(I)=EXP(Y)
      DEVX2=ALOG(CMGD)-CX2(I)
      SUMY=REMS(I)*((0.0098+((CEVX2**2)/252.2))**0.5)
      GO TO 16
C     COST ESTIMATE FOR SECONDARY AND STABILIZATION PONDS
   14 YY(I)=EXP(Y)
      DEVX1=ALOG(PE)-CX1(I)
      DEVX2=ALOG(CMGD)-CX2(I)
      CX1SQ=C11(I)*(DEVX1**2)
      CX2SQ=C22(I)*(DEVX2**2)
      C12XX=2.*C12(I)*DEVX1*DEVX2
      CNE(I)=1./CN(I)
      SUMY=REMS(I)*((CN(I)+CX1SQ+CX2SQ+C12XX)**.5)
   16 TSY=T(I)*SUMY
      YLIMIT(I)=EXP(Y-TSY)
      XLIMIT(I)=EXP(Y+TSY)
   20 CONTINUE
      DO 140 I=1,5
      YY(I)=1.2*YY(I)*CMGD*WPC(ICITY)/100.
      YLIMIT(I)=1.2*XLIMIT(I)*CMGD*WPC(ICITY)/100.
      YLIMIT(I)=1.2*YLIMIT(I)*CMGD*WPC(ICITY)/100.
      IF(OUT11.GT.0.0) GO TO 3319
      GO TO (71,88,92,97,105),I
   71 WRITE(6,72)JYEAR
   72 FORMAT(1H1,2X,'ESTIMATED COST OF CONSTRUCTIONS OF DIFFERENT PLANTS
     1 IN',2X,I5)
      WRITE(6,73)
   73 FORMAT(2X,60H**********************************************
     1*******  )
      WRITE(6,74)CMGD
   74 FORMAT(///,5X,'DESIGN CAPACITY IN MGD=',F7.3)
      WRITE(6,75) PE
   75 FORMAT(1H0,5X,'DESIGN POPULATION EQUIVALENT=',F10.2)
      WRITE(6,77)
   77 FORMAT(5X,52HCOMMENTS-ESTIMATED COST INCLUDES OUTFALL SEWERS,    )
      WRITE(6,78)
   78 FORMAT(5X,52HADMINISTRATIVE, ENGINEERING, AND LEGAL SERVICES COST)
      WRITE(6,79)
   79 FORMAT(5X,52HBUT NOT THE LAND COST                              )
      WRITE(6,83)YY(I)
   83 FORMAT(/////,5X,'ESTIMATED COST FOR PRIMARY PLANT=$',F12.1)
      WRITE(6,85)YLIMIT(I)
   85 FORMAT(1H0,5X,'LOWER LIMIT OF 95 PERCENT CONFIDENCE INTERVAL=$',1X
     1,F12.1)
      WRITE(6,87)XLIMIT(I)
   87 FORMAT(1H0,5X,'UPPER LIMIT OF 95 PERCENT CONFIDENCE INTERVAL=$',1X
     1,F12.1)
      GO TO 140
   88 WRITE(6,89)YY(I)
   89 FORMAT(/////,5X,'ESTIMATED COST FOR STABILIZATION POND=$',1X,F12.1
     1)
      WRITE(6,85)YLIMIT(I)
      WRITE(6,87)XLIMIT(I)
      GO TO 140
   92 WRITE(6,95) YY(I)
   95 FORMAT(/////,5X,'ESTIMATED COST FOR STD. RATE TRICKLING FILTER=$',
     12X,F12.1)
      WRITE(6,85)YLIMIT(I)
      WRITE(6,87)XLIMIT(I)
      GO TO 140
   97 WRITE(6,101) YY(I)
  101 FORMAT(/////,5X,'ESTIMATED COST FOR HIGH RATE TRICKLING=$',1X,F12.
     11)
      WRITE(6,85)YLIMIT(I)
      WRITE(6,87)XLIMIT(I)
      GO TO 140
  105 WRITE(6,108) YY(I)
  108 FORMAT(/////,5X,'ESTIMATED COSTS FOR ACTIVATED SLUDGE PLANT=$',2X,
     1F12.1)
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```
      WRITE(6,85)YLIMIT(I)
      WRITE(6,87)XLIMIT(I)
 3319 DUMMY=0.0
  140 CONTINUE
      IF(OUT11.GT.0.0) GO TO 3321
      DO 776 I=1,5
C*****************************************************************
C*                                                               *
C*     YY(1)   :TREATMENT PLNT.CONTR.COST:PRIMARY PLANT.SHAH-REID *
C*     YY(2)   :TREATMENT PLNT.CONTR COST:STAB. POND   .SHAH-REID *
C*     YY(3)   :TREATMENT PLNT.CONTR COST:SR TRICKLING  SHAH-REID *
C*     YY(4)   :TREATMENT PLNT.CONTR COST:HR TRICKLING  SHAH-REID *
C*     YY(5)   :TREATMENT PLNT.CONTR COST:ACT. SLUDGE   SHAH-REID *
C*     COST(17):TREATMENT PLNT.CONSTR.COST:PRIMARY: LOGAN ET.EL   *
C*     COST(18):TREATMENT PLNT CONSTR.COST:HR TRICKLE:LOGAN ET.EL *
C*     COST(19):TREATMENT PLNT CONSTR.COST:SR TRICKLE:LOGAN ET.EL *
C*     COST(20):TREATMENT PLNT CONSTR.COST:ACT.SLUDGE:LOGAN ET.EL *
C*     STAB    :TREATMENT PLNT CONSTR.COST:STAB.POND :PHS PUBL.   *
C*     ACTIV   :TREATMENT PLNT CONSTR.COST:ACT.SLUDGE:PHS PUBL.   *
C*     TRICKL  :TREATMENT PLNT CONSTR.COST:HR.TRICKLING:PHS:PUBL. *
C*                                                               *
  776 WRITE(6,777) B0(I),B1(I),B2(I),T(I),REMS(I),CX1(I),CX2(I),C11(I),
     1C12(I),C22(I),CN(I)
  777 FORMAT(11F10.5)
C         *    THE FOLLOWING PART OF THE SUBROUTINE ESTIMATES*
C         *    THE CONVENTIONAL SEWAGE TREATMENT PLANT COST  *
C         *    AS PER LOGAN ET. EL. REF: WPCF JOURNAL, VOL.34*
C         *    NO:9. THE PROGRAM UPDATES THE COST BY USING   *
C         *    WPC-STP COST INDEX.                           *
C         *                                                  *
C         ****************************************************
C
C*****************************************************************
      WRITE(6,141)
  141 FORMAT(1H1,10X,39HCONSTRUCTION COST ESTIMATE AS PER LOGAN)
 3321 DUMMY=0.0
C     READ ALL THE COEFFICIENTS IN REGRESSION EQUATIONS
      DO 144 I=1,20
  144 COST(I)=COEF(I)*(OMGD**EP(I))
C     UPDATE THE COSTS: INCLUDE THE NATIONAL AVERAGE INDEX:
C     THEN CONVERT IT TO REGIONAL INDEX
      DO 147 I=1,20
  147 COST(I)=OMGD*COST(I)*WPC(ICITY)/104.96
      COST(17)=COST(17)*0.7
      IF(OUT11.GT.0.0) GO TO 3323
      CALL OUTPUT(COST)
 3323 DUMMY=0.0
C         ****************************************************
C         *                                                  *
C         *    THIS PART OF THE SUBPROGRAM USES PHS METHOD    *
C         *    TO CALCULATE THE CONSTRUCTION COST OF THE     *
C         *    CONVENTIONAL TREATMENT PLANTS. IT USES WPC-STP*
C         *    COST INDEX TO UPDATE THE COST INTO REGIONAL    *
C         *    BASIS                                         *
C         *    REF: "MODERN SEWAGE TREATMENT PLANTS.HOW MUCH *
C         *    MUCH DO THEY COST. PUBLIC HEALTH SERVICE. US  *
C         *    DEPT. OF HEALTHE EDUCATION AND WELFARE.       *
C         *                                                  *
C         ****************************************************
      PW=-.4257
      STAB=OMGD**PW
      STAB=0.7*STAB
      STAB=128120.*STAB*WPC(ICITY)*OMGD/100.
      PW=-.22568
      ACTIV=OMGD**PW
      ACTIV=156820.*ACTIV*WPC(ICITY)*OMGD/100.
      WP=-.3201
      TRICKL=OMGD**WP
      TRICKL=242380.*TRICKL*WPC(ICITY)*OMGD/100.
      IF(OUT11.GT.0.0) GO TO 3327
      WRITE(6,201)
  201 FORMAT(1H1,////,10X,36HCOST ESTIMATE AS PER PHS PUBLICATION)
      WRITE(6,89)STAB
      WRITE(6,101) TRICKL
      WRITE(6,109)ACTIV
 3327 DUMMY=0.0
C ****************************************************************
C *                                                              *
C *       THE FOLLOWING PROGRAM ESTIMATES THE OPERATION COST     *
C *       OF THE CONVENTIONAL TREAT                              *
C *       OF THE CONVENTIONAL TREATMENT PLANTS@ THE US DEPT.@    *
C *       OF LABOR AVERAGE EARNINGS FOR NONSUPERVISORY           *
C *       WORKERS IN WATER STEAM AND SANITARY SYSTEMS            *
C *       HAVE BEEN USED TO ADJUST ALL OPERATING AND MAINTENAN   *
C *       HAVE BEEN USED TO ADJUST ALL OPERATING AND             *
C *       MAINTENANCE COST.                                      *
C *                                                              *
C ****************************************************************
C         TRCONS(I) : TRMNT. PLANT COST: AVERAGE OF ALL METHODS :
C                     I=1 : PRIMARY PLANT
C                     I=2 : STABILIZATION POND
C                     I=3 : H.R. TRICKLING FILTER
C                     I=4   S.R. TRICKLING FILTER
C                     I=5   ACTIVATED SLUDGE
C                     I=6 :  PACKAGE PLANT : CONTACT STABILIZATION
C                     I=7 :  PACKAGE PLANT : EXTENDED AERATION
      CALL PCKAGE(OMGD,PAKON,PAKOPR)
C
C
C         CALCULATE THE AVERAGE CONSTRUCTION COST
C
C
      TRCONS(1)  =(YY(1)+COST(17))/2.
      TRCONS(1)=TRCONS(1)*0.7
      TRCONS(2)  =(YY(2)+STAB)/2.
      TRCONS(3)  =(YY(4)+TRICKL)/2.
      TRCONS(4)  =(YY(3)+COST(19))/2.
      TRCONS(5)=(YY(5)+COST(20))/2.
      TRCONS(6)  =PAKON(1)
      TRCONS(7)  =PAKON(2)
      DO 255 ITREAT=1,7
      GO TO (242,243,245,248,249,251,253),ITREAT
  242 WRITE(6,256)TRCONS(ITREAT)
  256 FORMAT(1H1,//,5X,'CONSTRUCTION COST FOR PRIMARY TREATMENT PLANT  *
     1   $',F15.0)
      GO TO 255
  243 WRITE(6,257)TRCONS(ITREAT)
  257 FORMAT(//,2X,'CONSTRUCTION COST FOR STABILIZATION POND          *
     1$',F15.0)
      GO TO 255
  245 WRITE(6,258)TRCONS(ITREAT)
  258 FORMAT(//,2X,'CONSTRUCTION COST FOT  H.R. TRICKLING FILTER PLANT *
     1$',F15.0)
      GO TO 255
  248 WRITE(6,259)TRCONS(ITREAT)
  259 FORMAT(//,2X,'CONSTRUCTION COST FOR S.R. TRICKLING PLANT         *
     1$',F15.0)
      GO TO 255
  249 WRITE(6,261)TRCONS(ITREAT)
  261 FORMAT(//,2X,'CONSTRUCTION COST FOR ACTIVATED PLANT              *
     1$',F15.0)
      GO TO 255
  251 WRITE(6,263)TRCONS(ITREAT)
  263 FORMAT(//,2X,'CONSTRUCTION COST FOR  PACKAGE PLANT CONTACT STAB. *
     1$',F15.0)
      GO TO 255
  253 WRITE(6,264)TRCONS(ITREAT)
  264 FORMAT(//,2X,'CONSTRUCTION COST FOR PACKAGE PLANT : EXTENDED AIR *
     1$',F15.0)
  255 CONTINUE
      GO TO 9999
 9000 DUMMY=0.0
      OMGD=OMGD
      OMGD=SEWGYR(IYR)/365.0
      IF(OUT11.GT.0.0) GO TO 3329
      WRITE(6,241)
  241 FORMAT(1H1,10X,36HOPERATION COST ESTIMATE AS PER LOGAN)
 3329 DUMMY=0.0
      DO 244 I=1,20
  244 OCOST(I)=OBEF(I)*(OMGD**OP(I))
C
C
C  **********  UPDATE THE COST    **********************
C
C
      DO 247 I=1,20
  247 OCOST(I)= OMGD* OCOST(I)*AENW/2.17
      IF(OUT11.GT.0.0) GO TO 3339
      CALL OUTPUT(OCOST)
 3339 DUMMY=0.0
C     ****************************************************
C     *                                                  *
C     *   THIS PART OF THE SUBPROGRAM USES MICHAELS METHOD *
C     *   FOR ESTIMATING THE OPERATION COST               *
C     *   DEFINATIONS OF THE VARIABLES:                   *
C     *         CMICH(1)=   OPN. COST FOR CONVENTIONAL    *
C     *                     PRIMARY PLANT                 *
C     *         CMICH(2)=   OPN. COST FOR PRIMARY PLANT   *
C     *         TION POND                                 *
C     *         CMICH(3)=   OPN. COST FOR WASTE STABILIZA-  *
C     *         WITH OXIDATION LAGOON                     *
C     *         CMICH(4)=   OPN. COST FOR STD. RATE TRICKLING*
C     *         CMICH(5)=   OPN. COST FOR HIGH RATE TRICKLING*
C     *         CMICH(6)=   OPN. COST FOR ACTIVATED SLUDGE  *
C     *                                                   *
C     *****************************************************
      DO 260 I=1,6
      CMICH(I)=OMGD**EPM(CMI(I)
  260 CMICH(I)=CONS*(I)*CMICH(I)**4.4/2.8
      IF(OUT11.GT.0.0) GO TO 3341
      WRITE(6,265)
  265 FORMAT(////,5X,65HESTIMATED ANNUAL COST OF OPERATION AND MAINTENAN
     1CE AS PER MICHAEL)
      WRITE(6,266) CMICH(1)
  266 FORMAT(////,5X,'OPN COST FOR PRIMARY PLANT IN $/YEAR=',F10.3)
      WRITE(6,267) CMICH(2)
  267 FORMAT(5X,'OPN COST FOR PRIM+OXID. LAGOON IN $/YEAR=',F10.3)
      WRITE(6,268)CMICH(3)
  268 FORMAT(5X,'OPN COST FOR STAB. POND IN $/YEAR=',F10.3)
      WRITE(6,269) CMICH(4)
  269 FORMAT(5X,'OPN COST FOR S R TRICKLING IN $/YEAR=',F10.3)
      WRITE(6,270) CMICH(5)
  270 FORMAT(5X,'OPN COST FOR H R TRICKLING IN $/YEAR=',F10.3)
      WRITE(6,271) CMICH(6)
  271 FORMAT(5X,'OPN COST FOR ACTIV. SLUDGE IN $/YEAR=',F10.3)
 3341 DUMMY=0.0
C        OPNTRC(I): OPERATION COST FOR TRMNT PLANT: AVERAGE:
C                   I=1: PRIMARY
C                   I=2: STAB.POND
C                   I=3: H.R.TRICKLING
C                   I=4: S.R.TRICKLING
C                   I=5: ACTIVATED SLUDGE
C                   I=6: PACKAGE:CONTACT STAB
C                   I=7: PACKAGE: EXTENDED AERATION
      OPNTRC(1,IYR)=(OCOST(1)+CMICH(1))/2.
      OPNTRC(1,IYR)=0.7*OPNTRC(1,IYR)
      OPNTRC(2,IYR)=CMICH(3)
      OPNTRC(3,IYR)=(OCOST(2)+CMICH(5))/2.
      OPNTRC(4,IYR)=(OCOST(3)+CMICH(4))/2.
      OPNTRC(5,IYR)=(OCOST(4)+CMICH(6))/2.
      OPNTRC(6,IYR)=21560.0*OMGD+3978.
      OPNTRC(6,IYR)=0.6*OPNTRC(6,IYR)
      OPNTRC(7,IYR)=OPNTRC(6,IYR)
  280 FORMAT(1H1,///,10X,43HOPERATION COST OF TREATMENT PLANTS: AVERAGE)
      WRITE(6,266)OPNTRC(1,IYR)
      WRITE(6,268)OPNTRC(2,IYR)
      WRITE(6,270)OPNTRC(3,IYR)
      WRITE(6,269)OPNTRC(4,IYR)
      WRITE(6,271)OPNTRC(5,IYR)
      WRITE(6,285)OPNTRC(6,IYR)
  286 FORMAT(5X,'OPN. COST FOR PACKAGE EXTENDED AIR :  $/YEAR ',F12.3)
  285 FORMAT(5X,'OPN. COST FOR PACKAGE CONTACT STAB :  $/YEAR ',F12.3)
 9999 RETURN
      END
```

COUNT

```
      SUBROUTINE COUNT(IYR)
      DIMENSION AYP(20),PYR(20),PMONTH(12,20),PMONTH(12,20),
     1DUMP1(12,20),PUMP1(12,20)
      COMMON/BLOCK9/VCAAM(12,20),VCAYM(12,20),VCAMP(12,20),VTPLM(12,20),
     1ANDAYV(20),ANCAMV(20),AMTRLV(20),AMCABV(20),REVDV(365),TREDV(20),
     1TREV(20),PREVM(12,20)
      COMMON/BLK15/SEWGMO(12),SEWGYR(20),TD1(20),TP1(20)
      COMMON/BLOCK6/RAIN(365)
      COMMON/BLOCK5/PE(365)
      COMMON/BLOCK7/DUMP(365),TTPUM(365)
      KY=20
      AYP(IYR)=0.0
      PYR(IYR)=0.0
      TP1(IYR)=0.0
      TD1(IYR)=0.0
      DO 10 M=1,12
      PMONTH(M,IYR)=0.0
      PMONTH(M,IYR)=0.0
      PUMP1(M,IYR)=0.0
      DUMP1(M,IYR)=0.0
 10 CONTINUE
      DO 30 JDAY=1,365
      CALL MONTH(JDAY,MONTH)
      PMONTH(MONTH,IYR)=PMONTH(MONTH,IYR)+RAIN(JDAY)
      PMONTH(MONTH,IYR)=PMONTH(MONTH,IYR)+PE(JDAY)
      PUMP1(MONTH,IYR)=PUMP1(MONTH,IYR)+TTPUM(JDAY)
      DUMP1(MONTH,IYR)=DUMP1(MONTH,IYR)+DUMP(JDAY)
      AYP(IYR)=AYP(IYR)+RAIN(JDAY)
      PYR(IYR)=PYR(IYR)+PE(JDAY)
      TP1(IYR)=TP1(IYR)+TTPUM(JDAY)
      TD1(IYR)=TD1(IYR)+DUMP(JDAY)
 30 CONTINUE
      WRITE(6,105)IYR
105 FORMAT(1H1,5(/),15X,'SIMULATED MONTHLY RAIN-VISITTATION-SEWAGE AND
     1REVENUE FIGURES IN YEAR',I5)
      WRITE(6,110)IYR
110 FORMAT(4(/),10X,'     RAIN      PANEVAP        CABINS        CAMPING
     1    TRAILOR      OTHERS      SEWAGE        PUMP        DUMP       REVENUE',I
     13)
      WRITE(6,107)IYR
107 FORMAT(10X,'      (INCHES)   (INCHES)     (PERSON)     (PERSON)
     1(PERSON)   (PERSON)   (M.GALL)       (GALL)      (GALL)      (DOLLERS)'
     1,I1)
      DO 120 M=1,12
      SEWGMO(M)=SEWGMO(M)/(10.0**6.)
      WRITE(6,115)M,MONTH(M,IYR),PMONTH(M,IYR),VCAAM(M,IYR),VCAMP(M,IYR
     1),VTPLM(M,IYR),VDAYM(M,IYR),SEWGMO(M),PUMP1(M,IYR),DUMP1(M,IYR),RE
     1VM(M,IYR)
115 FORMAT(/,2X,'MONTH=',I3,3X,F5.2,4X,F6.2,4X,4(F11.0,1X),4X,F5.2,2X,
     1E12.2,1X,E12.2,F11.3)
120 CONTINUE
      SEWGYR(IYR)=SEWGYR(IYR)/(10.0**6.)
      WRITE(6,117)PYR(IYR),PYE(IYR),ANCAMV(IYR),ANCAMV(IYR),ANTRLV(IYR),
     1ANDAYV(IYR),SEWGYR(IYR),TP1(IYR),TD1(IYR),TREV(IYR)
117 FORMAT(//,2X,'TOTAL=',7X,F5.2,4X,F6.2,4X,4(F11.0,1X),4X,F5.2,2X,E1
     12.2,1X,E12.2,F11.3)
      IF(IYR.LT.KY) GO TO 999
      WRITE(6,40)
 40 FORMAT(1H1,///,5X,16H  SIMULATED RAIN)
      WRITE(6,45)
 45 FORMAT(//,2X,87H   YEAR    JAN    FEB    MAR    APR    MAY    JUN    JUL
     1  AUG    SEP    OCT    NOV    DEC    TOTAL)
      DO 210 KYR=1,KY
      WRITE(6,63)KYR,(RMONTH(M,KYR),M=1,12),RYR(KYR)
 63 FORMAT(1HO,I8,2X,12(F5.2,1X),F6.2)
210 CONTINUE
      WRITE(6,67)
 67 FORMAT(//,5X,26H  SIMULATED PANEVAPORATION)
      WRITE(6,65)
      DO 220 KYR=1,KY
      WRITE(6,60)KYR,(PMONTH(M,KYR),M=1,12),PYR(KYR)
220 CONTINUE
      WRITE(6,200)IYR
200 FORMAT(1H1,5X,'SIMULATED ANNUAL RAIN-PANEV-VISITATION-SEWAGE-REVEN
     1UE FIGURES FOR ALL YEARS',5X,I3)
      WRITE(6,110)IYR
      WRITE(6,107)IYR
      DO 300 I=1,KY
      WRITE(6,250)I,RYR(I),PYR(I),ANCABV(I),ANCAMV(I),ANTRLV(I),ANDAYV(I
     1),SEWGYR(I),TP1(IYR),TD1(IYR),TREV(I)
250 FORMAT(/,2X,'YEAR=',I3,6X,F5.2,4X,F6.2,4X,4(F11.0,1X),4X,F5.2,2X,E
     112.2,1X,E12.2,1X,F11.0)
300 CONTINUE
999 DUMMY=0.0
      RETURN
      END
```

PCKAGE

```
      SUBROUTINE PCKAGE(DMGD,PAKCN,PAKOPN)
      DIMENSION PAKON(2)
C     ***************************************************
C     *                                                 *
C     *   THIS SUBROUTINE ESTIMATES THE CONSTRUCTION COST   *
C     *   FOR PACKAGE PLANT.                            *
C     *   DEFN. OF THE VARIABLES :                      *
C     *   PAKON(1)=CONS COST                            *
C     *              STABILIZATION                      *
C     *   PAKON(2)=CONS. COST FOR PACKAGE PLANT WITH    *
C     *            EXTENDED AERATION                    *
C     *                                                 *
C     ***************************************************
      HUNGPD=DMGD*10000.
      PAKON(1)=416.*(HUNGPD**0.65426)
      ADDCST= PAKON(1)*1.1559
      PAKON(1)= PAKON(1)+ADDCST
      PAKON(2)=1140.0*(HUNGPD**0.49551)
      ADDCST=PAKON(2)*1.5939
      PAKON(2)= PAKON(2)+ADDCST
C     CALCULATE OPERATION COST
      PAKOPN= 2196O.*DMGD+3978.
      WRITE(6,1)
    1 FORMAT(1H1,10X,47HESTIMATED CONSTRUCTION COST FOR PACKAGE PLANT )
      WRITE(6,2) PAKON(1)
    2 FORMAT(/////,2X,'CONTACT STABILIZATION =  $',F15.2)
      WRITE(6,3) PAKON(2)
    3 FORMAT(/////,2X,'EXTENDED AERATION=$',F15.2)
      RETURN
      END
```

FINAL

```
      SUBROUTINE FINAL(SLUDGE,CL2,POWDMP,POWPMP,TREV,FIXED,RNTRST)
      DIMENSION SLUDGE(20),CL2(20),POWDMP(20),POWPMP(20),TREVL(20)
      COMMON/BLK5/PLNTOP(20),COSCOL(20),CIRPE(20),WORTHC(20),WORTHR(20),
     1OPNGRT(20)
      KY=20
      PCOST=FIXED
      PREV=0.0
      DO 10 I=1,KY
      OPNGRT(I)=PLNTOP(I)+SLUDGE(I)+CL2(I)+POWDMP(I)+POWPMP(I)+CUSCOL(I)
     1+CIRPE(I)
      AN=I
      AINT=RNTRST/100.
      WORTHC(I)=OPNGRT(I)/((1.0+AINT)**AN)
      WORTHR(I)=TREV(I)/((1.0+AINT)**AN)
      PCOST=PCOST+WORTHC(I)
      PREV=PREV+WORTHR(I)
 10 CONTINUE
      WRITE(6,200)
200 FORMAT(4(/),5X,43H SIMULATED OPERATIONS AND MAINTENANCE COSTS)
      WRITE(6,250)
250 FORMAT(//,10X,96H TREATMENT SLUDGE COLLECTION CHLORI- DUMP  PUMP I
     1RIGIATION  TOTAL   PR.WORTH   REVENUE  PR.WORTH)
      WRITE(6,251)
251 FORMAT(10X,96H PLANT    DISPOSE (TOTAL)   NATION              (TOTA
     1L)   OPN COST  (OPN.COST)          (REVENUE))
      WRITE(6,252)
252 FORMAT(10X,96H**********************************************
     1**********)
      DO 300 I=1,KY
      WRITE(6,280)I,PLNTOP(I),SLUDGE(I),COSCOL(I),CL2(I),POWDMP(I),POWPM
     1P(I),CIRPE(I),OPNGRT(I),WORTHC(I),TREV(I),WORTHR(I)
280 FORMAT(1X,'YEAR=',I3,F10.0,F7.0,F10.0,F8.0,F6.0,F6.0,5(F10.0))
300 CONTINUE
      WRITE(6,252)
      WRITE(6,310)PCOST,PREV
310 FORMAT(1X,'TOTAL',67X,F12.0,8X,F12.0)
      WRITE(6,320)RNTRST
320 FORMAT(///,10X,'PRESENT WORTH EVALUATED AT INTEREST (%)=',F6.1)
      PROFIT=PCOST-PREV
      WRITE(6,350)PROFIT
350 FORMAT(///,10X,'PRESENT WORTH OF COSTS - PRESENT WORTH OF REVENUE =
     1',F12.0)
      RETURN
      END
```

GAMMA

```
      SUBROUTINE GAMMA(ALPHA,BETA,STAR1,GAM,IX,PE,JKK)
      DIMENSION PE(365)
C     ***************************************************
C     *                                                 *
C     *   THIS SUBROUTINE GENERATES DAILY PAN EVAPORATION   *
C     *   ACCORDING TO GAMMA DISTRIBUTION               *
C     *                                                 *
C     ***************************************************
      IF(STAR1.GT.1.5) GO TO 60
      X3=1.
      IF(ALPHA.LE.1.5) GO TO 1
      IF(ALPHA.LE.19.) GO TO 2
      GO TO 3
    1 R=0.24797+(1.3473574*ALPHA)-(1.00004204*ALPHA**2)+(.5320317A*ALPHA
     1**3)-(.13671536*ALPHA**4)+(.01320964*ALPHA**5)
      GO TO 4
    2 R=0.64350+(0.45839602*ALPHA)-(0.02952801*ALPHA**2)+(0.00172718*ALP
     1HA**3)-(0.00005810*ALPHA**4)+(0.00000082*ALPHA**5)
      GO TO 4
    3 R=1.33608+(0.22499991*ALPHA)-(0.00230695*ALPHA**2)+(0.00001623*ALP
     1HA**3)-(.00000006*ALPHA**4)
    4 Y=1.0+(1.0/R)
      START=5.0
   12 IF(Y-1.01)10,50,15
   15 Y=Y-1.0
      X3=X3*Y
      GO TO 12
  110 GY=1.0+Y*(-0.5771017+Y*(0.985854+Y*(-0.8764218+Y*(0.8328212+
     1Y*(-0.5684729+Y*(0.2548205+Y*(-0.05149930)))))))
      X3=X3*GY/Y
   50 A=(X3/(ALPHA*BETA))**R
      R=1.0/R
      A=1.0/A
   60 CALL RANDU(IX,IY,YFL)
      GAM=(-A*ALOG(YFL))**R
      PE(JKK)=GAM
      PE(JKK)= PE(JKK) /0.82
      RETURN
      END
```

RANDU

```
      SUBROUTINE RANDU(IX,IY,YFL)
      IY=IX*65539
      IF(IY)5,6,6
    5 IY=IY+2147483647+1
    6 YFL=IY
      YFL=YFL*.4656613E-9
      IX=IY
      RETURN
      END
```

IRRI1

```
      SUBROUTINE IRRI1(NSOIL,NVARI,TREES)
      DIMENSION ACRE1(5,3,3),ACRE(5,3),TACRE(5),TREES(3,3)
      COMMON/BLOCK8/CONSIR(5),AIRRI(5),BIRRI(5)
      DO 20 METH=1,5
      CONSIR(METH)=0.0
      TACRE(METH)=0.0
      DO 20 NS=1,NSOIL
      ACRE1(METH,NS)=0.0
      DO 20 NV=1,NVARI
      ACRE(METH,NS,NV)=0.0
   20 CONTINUE
      DO 30 NS=1,NSOIL
      DO 30 NV=1,NVARI
      IF(TREES(NS,NV).LE.0.01GO TO 30
      ACRE(2,NS,NV)= TREES(NS,NV)*30.*30./43560.
      ACRE(3,NS,NV)=TREES(NS,NV)*40.*40./43560.
      ACRE(4,NS,NV)=ACRE(3,NS,NV)
      ACRE(5,NS,NV)=ACRE(3,NS,NV)
   30 CONTINUE
      DO 50 METH=2,5
      DO 40 NS=1,NSOIL
      DO 37 NV=1,NVARI
      ACRE1(METH,NS)=ACRE1(METH,NS)+ACRE(METH,NS,NV)
   37 CONTINUE
      TACRE(METH)=TACRE(METH)+ACRE1(METH,NS)
   40 CONTINUE
   50 CONTINUE
      DO 100 METHOD=2,5
      WRITE(6,65) METHOD
   65 FORMAT(///,10X,'ACRES IRRIGATED BY IRRIGATION TECHNIQUE',I3)
      WRITE(6,70)
   70 FORMAT(//,2X,44HTREES VARIETY:      1     2     3      TOTAL)
      DO 90 NS=1,NSOIL
      WRITE(6,80)NS,(ACRE(METHOD,NS,NV),NV=1,NVARI),ACRE1(METHOD,NS)
   80 FORMAT(/,8X,'SOIL PLOT=',I3,1X,3(F7.3,1X),F7.1)
   90 CONTINUE
      WRITE(6,95)METHOD,TACRE(METHOD)
   95 FORMAT(//,20X,'TOTAL ACRES IRRIGATED BY IRRIGATION TECHNIQUE=',I5,
     12X,F10.1)
  100 CONTINUE
C
C     ESTIMATE INSTALLATION COSTS FOR IRRIGATION SYSTEMS
C
      DO 200 M=1,5
      CONSIR(M)=AIRRI(M)*TACRE(M)+BIRRI(M)
  200 CONTINUE
      WRITE(6,210) METHOD
  210 FORMAT(1H1,///,10X,'INSTALLATION COSTS FOR IRRIGATION SYSTEMS',I3)
      DO 250 M=1,5
      WRITE(6,240)M,CONSIR(M)
  240 FORMAT(///,5X,'IRRIGATION TECHNIQUE=',I3,5X,'INS.COST= $',F15.1)
  250 CONTINUE
      RETURN
      END
```

RAINGN

```
      SUBROUTINE RAINGN(CYEAR,IX)
      INTEGER CYEAR
      DIMENSION FLAG(365)
      COMMON/BLOCK6/RAIN(365)
      COMMON/BLOCK1/FDAY(3),DD(3,12),RANGE(10,3,12),
     1START(10,3,12),DW(6,3,12),AINCRE(10,3,12)
C     ***********************************************
C     *                                             *
C     *   THIS SUBROUTINE GENERATES THE RAINY DAYS  *
C     *                                             *
C     ***********************************************
      DO 10 I=1,365
      FLAG(I)=0.0
   10 RAIN(I)=0.0
C        GENERATE THE RAIN SITUATION IN FIRST DAY
      CALL RANDU(IX,IY,YFL)
      RINI=YFL
      IF(RINI.GT.FDAY(CYEAR)) GO TO 15
      FLAG(1)=10.
   15 DO 100 I=1,365
      IF(FLAG(I).GT.0.0) GO TO 100
      CALL MMONTH(I,MONTH)
      IF(I.EQ.1) GO TO 20
      CALL RANDU(IX,IY,YFL)
      RINI=YFL
      IF(RINI.LE.DD(CYEAR,MONTH)) GO TO 99
C     ****  IT RAINED. HOW MUCH DID IT RAIN  *******
   20 FLAG(I)=10.
      CALL AMOUNT(MONTH,CYEAR,I,IX)
      RINI=0.0
      DO 30 J=1,6
      IF(RINI.GT.0.0) GO TO 30
      IJ=I+J
      IF(IJ.GT.365) GO TO 30
      FLAG(IJ)=10.
      CALL MMONTH(IJ,MONTH)
      CALL RANDU(IX,IY,YFL)
      RINI=YFL
      IF(RINI.LE.DW(J,CYEAR,MONTH)) GO TO 28
      CALL AMOUNT(MONTH,CYEAR,IJ,IX)
      GO TO 30
   28 RINI=10.
   30 CONTINUE
   99 FLAG(I)=10.
  100 CONTINUE
      RETURN
      END
```

MMONTH

```
      SUBROUTINE MMONTH(I,MONTH)
      IF(I.LE.31) MONTH=1
      IF(I.GT.31.AND.I.LE.59) MONTH=2
      IF(I.GT.59.AND.I.LE.90) MONTH=3
      IF(I.GT.90.AND.I.LE.120) MONTH=4
      IF(I.GT.120.AND.I.LE.151) MONTH=5
      IF(I.GT.151.AND.I.LE.181) MONTH=6
      IF(I.GT.181.AND.I.LE.212) MONTH=7
      IF(I.GT.212.AND.I.LE.243) MONTH=8
      IF(I.GT.243.AND.I.LE.273) MONTH=9
      IF(I.GT.273.AND.I.LE.304) MONTH=10
      IF(I.GT.304.AND.I.LE.334) MONTH=11
      IF(I.GT.334.AND.I.LE.365) MONTH=12
      RETURN
      END
```

OUTPUT

```
      SUBROUTINE OUTPUT(COST)
      DIMENSION COST(20)
      WRITE(6,150)
  150 FORMAT(////,5X,50HCOST ESTIMATE FOR PRELIMINARY TREATMENT IN DOLLA
     1RS)
      WRITE(6,152)COST(1)
  152 FORMAT(///,2X,'PRIMARY TREATMENT',2X,F15.2)
      WRITE(6,153) COST(2)
  153 FORMAT(2X,'HIGH RATE TRICKLING FILTERS',2X,F15.2)
      WRITE(6,154) COST(3)
  154 FORMAT(2X,'STD. RATE FILTERS',2X,F15.2)
      WRITE(6,155) COST(4)
  155 FORMAT(2X,'ACTIVATED SLUDGE',2X,F15.2)
      WRITE(6,160)
  160 FORMAT(//,5X,44HCOST ESTIMATE FOR PRIMARY TREATMENT IN DOLLERS)
      WRITE(6,152) COST(5)
      WRITE(6,153) COST(6)
      WRITE(6,154) COST(7)
      WRITE(6,155)COST(8)
      WRITE(6,170)
  170 FORMAT(//,5X,44HCOST ESTIMATE FOR SLUDGE HANDLING IN DOLLERS)
      WRITE(6,152)COST(9)
      WRITE(6,153) COST(10)
      WRITE(6,154)COST(11)
      WRITE(6,155)COST(12)
      WRITE(6,180)
  180 FORMAT(//,5X,43HCOST ESTIMATE FOR SECONDARY TREATMENT IN DOLLERS)
      WRITE(6,152)COST(13)
      WRITE(6,153)COST(14)
      WRITE(6,154)COST(15)
      WRITE(6,155)COST(16)
      WRITE(6,190)
  190 FORMAT(/////,5X,43HESTIMATED TOTAL CONSTRUCTION COST INCLUDING)
      WRITE(6,191)
  191 FORMAT(5X,44HSLUDGE HANDLING, CHLORINATION, ADMINSTRATION)
      WRITE(6,192)
  192 FORMAT(5X,11HAND GENERAL)
      WRITE(6,152) COST(17)
      WRITE(6,153)COST(18)
      WRITE(6,154)COST(19)
      WRITE(6,155)COST(20)
      RETURN
      END
```

SMSOL

```
      SUBROUTINE SMSOL(SUM2,NSOIL,NVARI,IYR,I,PRAIN,PPE,CONVRT,FACTOR)
      DIMENSION SSUM1(3)
      COMMON/BLOCK3/CANOPY(3,20),FC(3),WHC(3),SM(365,3,3),
     1APPLY(365,3,3),TREES(3,3),SMFST(3,3),SMLST(3,3),FLAGM(3,3)
      COMMON/BLOCK4/OUT3
C
C
C
C*************************************************************
C*                                                           *
C*       THIS SUBROUTINE IS CALLED ONLY WHEN THE VOLUME      *
C*       OF TOTAL EFFLUENT AVAILABLE IN A DAY IS NOT         *
C*       SUFFICIENT TO IRRIGATE ALL THE FIELDS TO MAXIMUM    *
C*       PERMITTABLE LEVELS. THIS SUBROUTINE ASSISTS TO      *
C*       DISTRIBUTE THE EFFLUENT IN THE FIELDS TO KEEP       *
C*       THE FIELDS AT A PERCENTAGE OF THEIR RESPECTIVE      *
C*       FIELD CAPACITIES                                    *
C*                                                           *
C*************************************************************
C
C
C
      DO 10 NS=1,NSOIL
      DO 10 NV=1,NVARI
      FLAGM(NS,NV)=10.
   10 CONTINUE
      SUM2=0.0
      IF(OUT3.LE.0.0) GO TO 15
      WRITE(6,1)
    1 FORMAT(///,2X,28HOUTPUT FROM SUBROUTINE SMSOL)
   15 DUMMY=0.0
      DO 100 NS=1,NSOIL
      SSUM1(NS)=0.0
      A=1./WHC(NS)
      B=(FC(NS)-WHC(NS))/WHC(NS)
      DO 90 NV=1,NVARI
      IF(TREES(NS,NV).LE.0.01) GO TO 90
      CONVRT=0.6233*CANOPY(NV,IYR)*TREES(NS,NV)
      IF(I.EQ.1.AND.IYR.EQ.1) GO TO 50
      IF(I.EQ.1.AND.IYR.GT.1) GO TO 60
      APPLY(I,NS,NV)=FACTOR*FC(NS)*CONVRT-SM(I-1,NS,NV)*CONVRT-RRAIN*
     1CONVRT+(A*FACTOR*FC(NS)-B)*0.7*PPE*CONVRT
      IF(APPLY(I,NS,NV).LT.0.0) GO TO 40
      FLAGM(NS,NV)=-10.
      GO TO 70
   40 FLAGM(NS,NV)=10.
      APPLY(I,NS,NV)=0.0
      GO TO 70
   50 APPLY(I,NS,NV)=FACTOR*FC(NS)*CONVRT-SMFST(NS,NV)*CONVRT-PRAIN*
     1CONVRT+(A*FACTOR*FC(NS)-B)*0.7*PPE*CONVRT
      IF(APPLY(I,NS,NV).LT.0.0) GO TO 55
      FLAGM(NS,NV)=-10.
      GO TO 70
   55 FLAGM(NS,NV)=10.
      APPLY(I,NS,NV)=0.0
      GO TO 70
   60 APPLY(I,NS,NV)=FACTOR*FC(NS)*CONVRT-SMLST(NS,NV)*CONVRT-RRAIN*
     1CONVRT+(A*FACTOR*FC(NS)-B)*0.7*PPE*CONVRT
      IF(APPLY(I,NS,NV).LT.0.0) GO TO 65
      FLAGM(NS,NV)=-10.
      GO TO 70
   65 FLAGM(NS,NV)=10.
      APPLY(I,NS,NV)=0.0
   70 DUMMY=1.0
      IF(OUT3.LE.0.01 GO TO 200
      WRITE(6,7)I,NS,NV,APPLY(I,NS,NV),A,B,FLAGM(NS,NV)
    7 FORMAT(///,2X,'DAY=',I3,2X,'NS=',I3,2X,'NV=',I3,2X,'APPLY=',F15.3,2X,
     1'A=',F15.5,2X,'B=',F10.6,2X,'FLAGM=',F5.1)
  200 DUMMY=0.0
      SSUM1(NS)=SSUM1(NS)+APPLY(I,NS,NV)
   90 CONTINUE
      IF(OUT3.LE.0.0) GO TO 300
      WRITE(6,8) SSUM1(NS),NS
    8 FORMAT(///,2X,'SSUM1(NS)=',F15.2,2X,'NS=',I3)
  300 DUMMY=0.0
      SUM2=SSUM1(NS)+SUM2
  100 CONTINUE
      IF(OUT3.LE.0.0) GO TO 400
      WRITE(6,2) FACTOR,SUM2
    2 FORMAT(///,2X,'FACTOR=',F5.3,2X,'SUM2=',F15.3)
  400 DUMMY=0.0
      RETURN
      END
```

TABLE

```
      SUBROUTINE TABLE(MIRRI,NCOLL,TRCONS,COLL,CONSIR,OPNTRC,POWCOL,TIRR
     1IC,SLUDGE,CL2OTH,CL2ACT,POWOMP,POWPMP,ANTRST,TREV,FIXTR,REPLTR)
      DIMENSION REPLTR(20)
      DIMENSION TRCONS(7),COLL(2),CONSTR(5),TFIX(10),OPNTRC(7,20),POWCOL
     1(20),TIRRIC(20,2),SLUDGE(20),CL2OTH(20),CL2ACT(20),POWOMP(20),POWP
     1MP(20),TREV(20)
      COMMON/BLK5/PLNTOP(20),COSCOL(20),CIRRF(20),WCRTHC(20),WCRTHA(20),
     1OPNGST(20)
      KY=20
C
C     PRIMARY AND STABILIZATION POND
C
      WRITE(6,9333)
 9333 FORMAT(1H1,10X,19HDECISION INVOLVES :)
      WRITE(6,5020)
 5020 FORMAT(20X,40HTREATMENT : PRIMARY + STABILIZATION POND)
      IF(NCOLL.EQ.2.AND.MIRRI.EQ.1) GO TO 5080
      IF(NCOLL.EQ.1.AND.MIRRI.EQ.2) GO TO 5140
      IF(NCOLL.EQ.2.AND.MIRRI.EQ.2) GO TO 5390
C
C     COST INFORMATION ON SUBMATIC WITH GRAVITY COLLECTION :PRIMARY+STAB
C
      WRITE(6,5030)NCOLL
 5030 FORMAT(20X,'COLLECTION SYSTEM : GRAVITY',I40)
      WRITE(6,5040)MIRRI
 5040 FORMAT(20X,'IRRIGATION SYSTEM : SUBMATIC',I40)
      WRITE(6,5050)MIRRI
 5050 FORMAT(///,20X,'DECISION INFEASIBLE : TREATMENT INADEQUATE TO MEET
     1IRRIGATION INPUT QUALITY : OUTPUT ON COST TERMINATED',I10)
C
C     COST INFO ON SUBMATIC WITH PRESSURE COLLECTION : PRIMARY+STAB
C
      GO TO 5405
 5080 WRITE(6,5130)NCOLL
 5130 FORMAT(20X,'COLLECTION SYSTEM : PRESSURE',I40)
      WRITE(6,5140)MIRRI
 5140 FORMAT(20X,'IRRIGATION SYSTEM : SUBMATIC',I40)
      WRITE(6,5050)MIRRI
      GO TO 5405
C
C     COST INFO ON SPRINKLER WITH GRAVITY COLLECTION : PRIMARY+STAB
C
 5180 WRITE(6,5030)NCOLL
      WRITE(6,5240)MIRRI
 5240 FORMAT(20X,'IRRIGATION SYSTEM : SPRINKLER',I40)
C
C     FIXED COST TABULATION: SPRINKLER:GRAVITY:PRIMARY+STAB
C
      WRITE(6,5280)TRCONS(1)
 5280 FORMAT(4(/),10X,'FIXED COST : CONSTRUCTION : PRIMARY : $',F15.1)
      WRITE(6,5285)TRCONS(2)
 5285 FORMAT(10X,'            : STAB POND              : $',F15.1)
      WRITE(6,5290)COLL(1)
 5290 FORMAT(10X,'            : GRAVITY COLLECTION     : $',F15.1)
      WRITE(6,5295)CONSIR(4)
 5295 FORMAT(10X,'  : SOLID SET : AUTO : SPRINKLER     : $',F15.1)
      TFIX(1)=TRCONS(1)+TRCONS(2)+COLL(1)+CONSIR(4)
C     TFIX(1)=TOTAL FIXED COST IN PRIMARY + STAB
C                           WITH GRAVITY COLLECTION
C                           AND  SPRINKLER IRRIGATION
      WRITE(6,5300)TFIX(1)
 5300 FORMAT(/,10X,'TOTAL FIXED COST                    : $',F15.1)
      DO 5310 K=1,KY
      PLNTOP(K)=OPNTRC(1,K)+OPNTRC(2,K)
      COSCOL(K)=POWCOL(K)
      CIRRF(K)=TIRRIC(K,2)
 5310 CONTINUE
      FIXED=TFIX(1)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,ANTRST)
      GO TO 5405
C
C     COST INFO ON SPRINKLER WITH PRESSURE COLLECTION : PRIMARY + STAB
C
 5380 WRITE(6,5130)NCOLL
      WRITE(6,5240)MIRRI
      WRITE(6,5280)TRCONS(1)
      WRITE(6,5295)TRCONS(2)
      WRITE(6,5385)COLL(2)
 5385 FORMAT(10X,'      :PRESSURE COLLECTION     : $',F15.1)
      WRITE(6,5295)CONSIR(4)
      TFIX(2)=TRCONS(1)+TRCONS(2)+COLL(2)+CONSIR(4)
C
C     TFIX(2)=TOTAL FIXED COST IN PRIMARY + STAB
C                           WITH PRESSURE COLLECTION
C                           AND  SPRINKLER IRRIGATION
C
      WRITE(6,5300)TFIX(2)
      DO 5387 K=1,KY
      PLNTOP(K)=OPNTRC(1,K)+OPNTRC(2,K)
      COSCOL(K)=POWCOL(K)
 5387 CIRRF(K)=TIRRIC(K,2)
      FIXED=TFIX(2)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,ANTRST)
C
C     MRTF AND STABILIZATION POND
C
 5405 WRITE(6,5003)
      WRITE(6,5410)
 5410 FORMAT(20X,40HTREATMENT : MRTF + STABILIZATION POND   )
      IF(NCOLL.EQ.2.AND.MIRRI.EQ.1) GO TO 5480
      IF(NCOLL.EQ.1.AND.MIRRI.EQ.2) GO TO 5500
      IF(NCOLL.EQ.2.AND.MIRRI.EQ.2) GO TO 5540
C
C     COST INFO ON SUBMATIC WITH GRAVITY COLLECTION :MRTF + STAB
C
      WRITE(6,5030)NCOLL
      WRITE(6,5040)MIRRI
      WRITE(6,5420)TRCONS(3)
 5420 FORMAT(4(/),10X,'FIXED COST :CONSTRUCTION  :MRTF     : $',F15.1)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5290)COLL(1)
      WRITE(6,5425)CONSIR(1)
 5425 FORMAT(10X,'  : 3X3 SUBMATIC : AUTO : GRASS          : $',F15.1)
      WRITE(6,5430)CONSIR(3)
 5430 FORMAT(10X,'  : 40*40 SUBMATIC:AUTO : TREES          : $',F15.1)
```

```
      TFIX(3)=TRCONS(3)+TRCONS(2)+COLL(1)+CONSIR(1)+CONSIR(3)
C
C     TFIX(3)=TOTAL FIXED COST:SUBMATIC-GRAVITY-HRTF-STAB
C
C
      WRITE(6,5300)TFIX(3)
      DO 5435 K=1,KY
      PLNTOP(K)=OPNTRC(3,K)+OPNTRC(2,K)
      COSCOL(K)=POWCOL(K)
      CIRPE(K)=TIRRIC(K,2)
 5435 CONTINUE
      FIXED=TFIX(3)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,RNTRST)
      GO TO 5350
C
C     COST INFO ON SUBMATIC WITH PRESSUPE COLLECTION :HRTF + STAB
C
 5480 WRITE(6,5130)NCOLL
      WRITE(6,5140)NIRRI
      WRITE(6,5420)TRCONS(3)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5385)COLL(2)
      WRITE(6,5290)CONSIR(1)
      WRITE(6,5430)CONSIR(3)
      TFIX(4)=TRCONS(3)+TRCONS(2)+COLL(2)+CONSIR(1)+CONSIR(3)
C
C     TFIX(4)=TOTAL FIXED COST : SUBMATIC-PRESSURE-HRTF-STAB
C
      WRITE(6,5300)TFIX(4)
      DO 5485 K=1,KY
      PLNTOP(K)=OPNTRC(3,K)+OPNTRC(2,K)
      COSCOL(K)=POWCOL(K)
      CIRPE(K)=TIRRIC(K,2)
 5485 CONTINUE
      FIXED=TFIX(4)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,RNTRST)
      GO TO 5550
C
C     COST INFO ON SPRINKLER-GRAVITY-HRTF-STAB
C
 5500 WRITE(6,5030)NCOLL
      WRITE(6,5240)NIRRI
      WRITE(6,5420)TRCONS(3)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5290)COLL(1)
      WRITE(6,5295)CONSIR(4)
      TFIX(5)=TRCONS(3)+TRCONS(2)+COLL(1)+CONSIR(4)
C
C     TFIX(5)=TOTAL FIXED COST : SPRINKLER-GRAVITY-HRTF-STAB
C
      WRITE(6,5300)TFIX(5)
      DO 5510 K=1,KY
 5510 PLNTOP(K)=OPNTRC(3,K)+OPNTRC(2,K)
      FIXED=TFIX(5)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,RNTRST)
      GO TO 5550
C
C     COST INFO ON SPRINKLER-PRESSURE-HRTF-STAB
C
 5540 WRITE(6,5130)NCOLL
      WRITE(6,5240)NIRRI
      WRITE(6,5420)TRCONS(3)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5385)COLL(2)
      WRITE(6,5295)CONSIR(4)
      TFIX(6)=TRCONS(4)+TRCONS(2)+COLL(2)+CONSIR(4)
C
C     TFIX(6)=TOTAL FIXED COST:SPRINKLER:PRESSURE:HRTF:STAB
C
      WRITE(6,5300)TFIX(6)
      DO 5545 K=1,KY
 5545 PLNTOP(K)=OPNTRC(3,K)+OPNTRC(2,K)
      FIXED=TFIX(6)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,RNTRST)
C
C     SRTF AND STABILIZATION POND
C
 5550 WRITE(6,5003)
      WRITE(6,5550)
 5560 FORMAT(20X,40HTREATMENT : SRTF + STABILIZATION POND   )
      IF(NCOLL.EQ.2.AND.NIRRI.EQ.1) GO TO 5610
      IF(NCOLL.EQ.1.AND.NIRRI.EQ.2) GO TO 5620
      IF(NCOLL.EQ.2.AND.NIRRI.EQ.2) GO TO 5640
C
C     COST INFO ON SUBMATIC WITH GRAVITY :SRTF + STAB
C
      WRITE(6,5030)NCOLL
      WRITE(6,5040)NIRRI
      WRITE(6,5570)TRCONS(4)
 5570 FORMAT(4(/),10X,'FIXED COST : CONSTRUCTION :SRTF      : $',F15.1)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5290)COLL(1)
      WRITE(6,5425)CONSIR(1)
      WRITE(6,5430)CONSIR(3)
      TFIX(7)=TRCONS(4)+TRCONS(2)+COLL(1)+CONSIR(1)+CONSIR(3)
C
C     TFIX(7)=TOTAL FIXED COST:SUBMATIC-GRAVITY-SRTF-STAB
C
      WRITE(6,5303)TFIX(7)
      DO 5575 K=1,KY
      PLNTOP(K)=OPNTRC(4,K)+OPNTRC(2,K)
 5575 CONTINUE
      FIXED=TFIX(7)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,RNTRST)
      GO TO 5650
C
C     COST IFFORMATION ON SUBMATIC-PRESSURE-SRTF-STAB
C
 5610 WRITE(6,5130)NCOLL
      WRITE(6,5140)NIRRI
      WRITE(6,5570)TRCONS(4)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5385)COLL(2)
      WRITE(6,5290)CONSIR(1)
      WRITE(6,5430)CONSIR(3)
      TFIX(8)=TRCONS(4)+TRCONS(2)+COLL(2)+CONSIR(1)+CONSIR(3)
C
C     TFIX(8)=TOTAL FIXED COST : SUBMATIC-PRESSURE-SRTF-STAB
C
      WRITE(6,5300)TFIX(8)
      DO 5615 K=1,KY
 5615 PLNTOP(K)=OPNTRC(4,K)+OPNTRC(2,K)
      FIXED=TFIX(8)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,RNTRST)
      GO TO 5650
C
C     COST INFO ON SPRINKLER-GRAVITY-SRTF-STAB
C
 5620 WRITE(6,5030)NCOLL
      WRITE(6,5240)NIRRI
      WRITE(6,5570)TRCONS(4)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5290)COLL(1)
      WRITE(6,5295)CONSIR(4)
      TFIX(9)=TRCONS(4)+TRCONS(2)+COLL(1)+CONSIR(4)
C
C     TFIX(9)=TOTAL FIXED COST : SPRINKLER-GRAVITY-SRTF-STAB
C
      WRITE(6,5300)TFIX(9)
      DO 5630 K=1,KY
 5630 PLNTOP(K)=OPNTRC(4,K)+OPNTRC(2,K)
      FIXED=TFIX(9)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,RNTRST)
      GO TO 5650
C
C     COST INFO ON SPRINKLER-PRESSURE-SRTF-STAB
C
 5640 WRITE(6,5130)NCOLL
      WRITE(6,5240)NIRRI
      WRITE(6,5570)TRCONS(4)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5385)COLL(2)
      WRITE(6,5295)CONSIR(4)
      TFIX(10)=TRCONS(4)+TRCONS(2)+COLL(2)+CONSIR(4)
C
C     TFIX(10)=TOTAL FIXED COST: SPRINKLER-PRESSURE-SRTF-STAB
C
      WRITE(6,5300)TFIX(10)
      DO 5645 K=1,KY
 5645 PLNTOP(K)=OPNTRC(4,K)+OPNTRC(2,K)
      FIXED=TFIX(10)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,RNTRST)
C
C     ACTIVATED SLUDGE AND STABILIZATION POND
C
 5650 WRITE(6,5003)
      WRITE(6,5650)
 5680 FORMAT(20X,40HTREATMENT : ACT.. SLUDGE  +  STAB. POND  )
      IF(NCOLL.EQ.2.AND.NIRRI.EQ.1) GO TO 5710
      IF(NCOLL.EQ.1.AND.NIRRI.EQ.2) GO TO 5720
      IF(NCOLL.EQ.2.AND.NIRRI.EQ.2) GO TO 5740
C
C     COST INFO ON SUBMATIC-GRAVITY-ACTIVATED-STAB
C
      WRITE(6,5030)NCOLL
      WRITE(6,5040)NIRRI
      WRITE(6,5670)TRCONS(5)
 5670 FORMAT(4(/),10X,'FIXED COST : CONSTRUCTION:ACT.SLUDGE: $',F15.1)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5290)COLL(1)
      WRITE(6,5425)CONSIR(1)
      WRITE(6,5430)CONSIR(3)
      TFIX(11)=TRCONS(5)+TRCONS(2)+COLL(1)+CONSIR(1)+CONSIR(3)
C
C     TFIX(11)=TOTAL FIXED COST : SUBMATIC:GRAVITY:ACT:DTAB
C
      WRITE(6,5300)TFIX(11)
      DO 5675 K=1,KY
      PLNTOP(K)=OPNTRC(5,K)+OPNTRC(2,K)
 5675 CONTINUE
      FIXED=TFIX(11)
      CALL FINAL(SLUDGE,CL2ACT,POWOMP,POWPMP,TREV,FIXED,RNTRST)
      GO TO 5750
C
C     COST INFO ON SUBMATIC-PRESSURE-ACTIV-STAB
C
 5710 WRITE(6,5130)NCOLL
      WRITE(6,5140)NIRRI
      WRITE(6,5670)TRCONS(5)
      WRITE(6,5285) TRCONS(2)
      WRITE(6,5385)COLL(2)
      WRITE(6,5290)CONSIR(1)
      WRITE(6,5430)CONSIR(3)
      TFIX(12)=TRCONS(5)+COLL(2)+TRCONS(2)+CONSIR(1)+CONSIR(3)
C
C     TFIX(12)=TOTAL FIXED COST : SUBMATIC:PRESSURE:ACTIV:STAB
C
      WRITE(6,5300)TFIX(12)
      DO 5715 K=1,KY
 5715 PLNTOP(K)=OPNTRC(5,K)+OPNTRC(2,K)
      FIXED=TFIX(12)
      CALL FINAL(SLUDGE,CL2ACT,POWOMP,POWPMP,TREV,FIXED,RNTRST)
      GO TO 5750
C
C     COST INFO ON SPRINKLER-GRAVITY-ACTIV-STAB
C
 5720 WRITE(6,5030)
      WRITE(6,5240)NIRRI
      WRITE(6,5670)TRCONS(5)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5290)COLL(1)
      WRITE(6,5295)CONSIR(4)
      TFIX(13)=TRCONS(5)+TRCONS(2)+COLL(1)+CONSIR(4)
      WRITE(6,5300)TFIX(13)
      DO 5730 K=1,KY
 5730 PLNTOP(K)=OPNTRC(5,K)+OPNTRC(2,K)
      FIXED=TFIX(13)
      CALL FINAL(SLUDGE,CL2ACT,POWOMP,POWPMP,TREV,FIXED,RNTRST)
      GO TO 5750
C
C     TFIX(13)=TOTAL FIXED COST : SPRINKLER-GRAVITY-ACTIV-STAB
C
```

```
C
C     COST INFO ON SPRINKLER-PRESSURE-ACTIV-STAB
C
 5740 WRITE(6,5130)MCOLL
      WRITE(6,5240)MIRRI
      WRITE(6,5670)TRCONS(5)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5365)COLL(2)
      WRITE(6,5295)CONSIR(4)
      TFIX(14)=TRCONS(5)+TRCONS(2)+COLL(2)+CONSIR(4)
      WRITE(6,5300)TFIX(14)
C
C     TFIX(14)=TOTAL FIXED COST :SPRINKLER:PRESSURE:ACTIV:STAB
C
      DO 5745 K=1,KY
 5745 PLNTOP(K)=OPNTRC(5,K)+OPNTRC(2,K)
      FIXED=TFIX(14)
      CALL FINAL(SLUDGE,CL2ACT,POWOMP,POWPMP,TREV,FIXED,RNTRST)
C
C     PACKAGE PLANT AND STABILIZATION POND
C
 5750 WRITE(6,5003)
      WRITE(6,5710)
 5783 FORMAT(2/X,40HTREATMENT :PACKAGE: CONTACT STAB+STAB   )
      IF(MCOLL.EQ.2.AND.MIRRI.EQ.1) GO TO 5810
      IF(MCOLL.EQ.1.AND.MIRRI.EQ.2) GO TO 5820
      IF(MCOLL.EQ.2.AND.MIRRI.EQ.2) GO TO 5840
C
C     COST INFO ON SUBMATIC-GRAVITY-PACKAGE-STAB
C
      WRITE(6,5030)MCOLL
      WRITE(6,5341)MIRRI
      WRITE(6,5770)TRCONS(6)
 5773 FORMAT(4(/),13X,'FIXED COST : CONSTRUCTION   PACKAGE : $',F15.1)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5425)CONSIR(1)
      WRITE(6,5430)CONSIR(3)
C
      TFIX(15)=TRCONS(6)+TRCONS(2)+COLL(1)+CONSIR(1)+CONSIR(3)
C
      DO 5775 K=1,KY
      PLNTOP(K)=OPNTRC(6,K)+OPNTRC(2,K)
 5775 CONTINUE
      FIXED=TFIX(15)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,RNTRST)
      GO TO 7001
C     COST INFO ON SUBMATIC-PRESSURE-PACK-STAB
C
 5810 WRITE(6,5130)MCOLL
C     TFIX(15)=TOTAL FIXED COST : SUBMATIC:GRAVITY:PACK:STAB
C
      WRITE(6,5300)TFIX(15)
      WRITE(6,5240)COLL(1)
      WRITE(6,5140)MIRRI
      WRITE(6,5770)TRCONS(6)
      WRITE(6,5385)COLL(2)
      WRITE(6,5290)CONSIR(1)
      WRITE(6,5430)CONSIR(3)

      TFIX(16)=TRCONS(6)+TRCONS(2)+COLL(2)+CONSIR(1)+CONSIR(3)
      WRITE(6,5300)TFIX(16)
C
C     TFIX(16)= TOTAL FIXED COST :SUBMATIC:PRESSURE:PACK:STAB
C
      DO 5815 K=1,KY
 5815 PLNTOP(K)=OPNTRC(6,K)+OPNTRC(2,K)
      FIXED=TFIX(16)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,RNTRST)
      GO TO 7001
C
C     COST INFO ON SPRINKLER:GRAVITY:PACK:STAB
C
 5820 WRITE(6,5030)
      WRITE(6,5240)MIRRI
      WRITE(6,5770)TRCONS(6)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5290)COLL(1)
      WRITE(6,5295)CONSIR(4)
      TFIX(17)=TRCONS(6)+TRCONS(2)+COLL(1)+CONSIR(4)
      WRITE(6,5300)TFIX(17)
C
C     TFIX(17)=TOTAL FIXED COST :SPRINKLER:GRAVITY:PACK:STAB
C
      DO 5830 K=1,KY
 5830 PLNTOP(K)=OPNTRC(6,K)+OPNTRC(2,K)
      FIXED=TFIX(17)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,RNTRST)
      GO TO 7001
C
C     COST INFO ON SPRINKLER-PRESSURE-PACK-STAB
C
 5840 WRITE(6,5130)MCOLL
      WRITE(6,5240)MIRRI
      WRITE(6,5770)TRCONS(6)
      WRITE(6,5285)TRCONS(2)
      WRITE(6,5385)COLL(2)
      WRITE(6,5295)CONSIR(4)
      TFIX(18)=TRCONS(6)+TRCONS(2)+COLL(2)+CONSIR(4)
      WRITE(6,5300)TFIX(18)
C
C     TFIX(18)=TOTAL FIXED COST : SPRINKLER:PRESSURE:ACTIV:STAB
C
      DO 5845 K=1,KY
 5845 PLNTOP(K)=OPNTRC(6,K)+OPNTRC(2,K)
      FIXED=TFIX(18)
      CALL FINAL(SLUDGE,CL2OTH,POWOMP,POWPMP,TREV,FIXED,RNTRST)
 7001 RETURN
      END
```

APPENDIX C

DESIGN CRITERIA AND COST ANALYSIS FOR SEWAGE COLLECTION SYSTEMS

TABLE C-1

PRESSURE SEWER SYSTEM DESIGN: HYDRAULIC ANALYSIS AND PIPE SCHEDULE, EAST BANK OF WHITE RIVER LAKE, TEXAS[a]

Pipe Section East Side of Lake	Length	# of Homes in Section	Accumulative # of Homes upto this Section	# of pumps connected in section	Accumulative number of pumps upto this section	# of pumps acting simultaneously	Design Flow	Pipe Diameter	Velocity	Friction Loss	Friction Loss thru section	Misc. Head Loss	Total Head Loss thru section	Potential Head Loss	Cumulative Head Loss	Comment
	ft						gpm	inch	fps	ft/100ft	ft	ft	ft	ft	ft	
E1	379	3	3	1	1	1	10	1.25	2.00	1.78	6.74	0.34	7.08	-	7.08	
E2	666	9	12	4	5	3	30	2.00	2.87	1.81	12.05	0.60	12.65	-	19.73	
E3	182	3	15	1	6	3	30	2.00	2.87	1.81	3.29	0.16	3.45	-	23.18	
E4	515	8	23	2	8	3	30	2.00	2.87	1.81	9.32	0.47	9.78	-	32.96	
E5	758	12	35	3	11	4	40	2.50	2.68	1.28	9.70	0.48	10.18	11.0	54.14	
E6	696	0	35	0	11	4	40	2.50	2.68	1.28	8.90	0.45	9.35	-	63.49	
E7	394	0	35	0	11	4	40	2.50	2.68	1.28	5.04	0.25	5.29	-	68.78	Boosting
E8	455	0	35	0	11	4	40	2.50	2.68	1.28	5.82	0.29	6.11	-	6.11	Reqd.
E9	515	4	39	1	12	4	40	2.50	2.68	1.28	6.59	0.33	6.92	-	13.03	
E10	666	28	67	6	18	5	50	3.00	2.17	0.67	4.43	0.22	4.65	-	17.68	
E11	666	10	77	2	20	5	50	3.00	2.17	0.67	4.43	0.22	4.65	-	22.33	
E12	666	12	89	3	23	5	50	3.00	2.17	0.67	4.43	0.22	4.65	-	26.98	
E13	425	7	96	2	25	5	50	3.00	2.17	0.67	2.83	0.14	2.97	-	29.95	
E14	600	15	111	3	28	6	60	3.00	2.60	0.94	5.63	0.28	5.91	-	35.86	
E15	1692	12	123	4	32	6	60	3.00	2.60	0.94	15.92	0.79	16.71	-	52.57	
E16	1242	0	123	0	32	6	60	3.00	2.60	0.94	11.65	0.58	12.23	-	64.80	Boosting
E17	1272	0	123	0	32	6	60	3.00	2.60	0.94	11.93	0.59	12.52	-	12.52	Reqd.
E18	424	0	123	0	32	6	60	3.00	2.60	0.94	3.98	0.20	4.28	-	16.70	
E19	300	0	123	0	32	6	60	3.00	2.60	0.94	2.80	0.14	2.94	-	19.64	
E20	1969	1	124	1	33	6	60	3.60	2.60	0.94	19.40	0.97	20.37	25.0	65.01	

[a] The design is based on current facilities, Dec. 1974

TABLE C-2

PRESSURE SEWER SYSTEM DESIGN: HYDRAULIC ANALYSIS AND PIPE SCHEDULE, WEST BANK OF WHITE RIVER LAKE, TEXAS[a]

Pipe Section West Side of Lake	Length	# of Homes in Section	Accumulative # of Homes upto this Section	# of pumps connected in section	Accumulative number of pimps into this section	# of pumps acting simultaneously	Design Flow	Pipe Diameter	Velocity	Friction Loss	Friction Loss thru section	Total Misc. Head Loss	Head Loss thru section	Potential Head Loss	Cumulative Head Loss	Comment
	ft						gpm	inch	fps	ft/100ft	ft		ft	ft	ft	
W1	545	8	8	2	2	2	20	1.5	3.16	2.96	16.13	.80	16.13	11	27.93	
W2	1151	19	27	4	6	3	30	2	2.87	1.81	20.8	1.04	21.84	0	49.77	
W3	666	11	38	3	9	4	40	2.5	2.68	1.28	8.52	.43	8.95	0	58.72	
W4	900	9	47	2	11	4	40	2.5	2.68	1.28	11.52	.58	12.10	0	70.82	Boost-
W5	1000	0	47	0	11	4	40	2.5	2.68	1.28	12.8	.64	13.44	0	13.44	ing
W6	2060	7	54	2	13	4	40	2.5	2.68	1.28	26.37	1.32	27.69	0	41.13	Reqd.
W7	485	7	61	2	15	4	40	2.15	2.68	1.28	6.21	.31	6.52	0	47.65	
W8	300	10	71	3	18	5	50	3	2.17	.665	1.99	.09	2.08	0	49.73	
W9	970	19	90	4	22	5	50	3	2.17	.665	6.45	.32	6.77	0	56.5	
W10	910	19	109	4	26	5	50	3	2.17	.665	6.05	.30	6.35	0	62.85	Boost-
W11	1333	19	128	4	30	6	60	3	2.6	.938	12.50	.63	13.13	0	13.13	ing
W12	1636	10	138	3	33	6	60	3	2.6	.938	15.34	.77	16.11	11	40.24	Reqd.
W13	1666	0	138	0	33	6	60	3	2.6	.938	15.62	.78	16.4	0	56.64	Boost-
W14	760	1	139	1	34	6	60	3	2.6	.938	7.12	.37	7.49	25	32.49	ing
W15	600	0	139	0	34	6	60	3	2.6	.938	5.628	.28	5.90	--	38.4	Reqd.

[a] The design is based on current facilities, Dec, 1974

TABLE C-3

ESTIMATE DEPT OF CUTS FOR VARIOUS SECTIONS OF SEWER MAIN IN GRAVITY COLLECTION: WEST BANK OF WHITE RIVER LAKE, TEXAS[a]

Pipe Section	Total Length in ft.	Length of the section at various ranges of depth of cuts in ft						Depth of the end joining the next section.	Comments
		0-6	6-8	8-10	10-12	12-14	14-16		
W1	450	450	-	-	-	-	-	2.72	
W2	450	450	-	-	-	-	-	5.44	
W3	590	100	333	157	-	-	-	8.94	
W4	450	-	-	176	274	-	-	11.65	
W5a	58	-	-	-	58	-	-	12.	Lift Reqd.
b	638	638	-	-	-	-	-	3.83	
W6	363	363	-	-	-	-	-	6	
W7	212	-	212	-	-	-	-	727	
W8	450	-	120	330	-	-	-	10.	Lift Reqd.
W9	300	300	-	-	-	-	-	1.8	
W10	500	500	-	-	-	-	-	4.8	
W11a	200	200	-	-	-	-	-	6	Ground Surface has Sufficient slope
W11b	150	150	-	-	-	-	-	0.9	
W12a	290	290	-	-	-	-	-	2.64	Ground Surface
b	290	290	-	-	-	-	-	1.74	has sufficient Slope
W13	515	515	-	-	-	-	-	4.13	
W14	515	195	320	-	-	-	-	7.92	
W15a	180	-	13	167	-	-	-	9.00	
W15b	166	-	-	166	-	-	-	10.0	
W16a	333	-	-	-	333	-	-	12.0	Lift Reqd.
b	267	267	-	-	-	-	-	1.6	
W17	660	660	-	-	-	-	-	5.56	
W18	1000	73	333	333	261	-	-	11.56	
W19a	407	-	-	-	74	333	-	14.	
W19b	743	743	-	-	-	-	-	4.45	
W20	750	257	333	160	-	-	-	8.96	
W21	600	-	-	174	333	93	-	14.56	
W22	200	-	-	-	-	-	200	15.76	Lift Reqd.
W23	450	450	-	-	-	-	-	2.7	
W24	450	450	-	-	-	-	-	5.4	
W25	450	100	333	17	-	-	-	8.1	
W26	780	-	-	316	333	131	-	12.78	Lifted to treatment plant.

[a] 6 inch PVC pipe 40 Sch. at a slope of 0.006 ft/ft.

TABLE C-4

DEPTH OF CUTS FOR VARIOUS SECTIONS OF MAIN LINE IN GRAVITY SEWERS: EAST BANK OF WHITE RIVER LAKE, TEXAS[a]

Pipe Section	Total Length in ft.	Length of Pipe Section In Various Ranges of Depth of Cuts in ft.						Depth of the Terminal end Below Ground	Comments
		0-6	6-8	8-10	10-12	12-14	14-16		
E 1	424	424	-	-	-	-	-	2.54	
E2	650	576	74	-	-	-	-	6.445	
E3	900	-	259	333	308	-	-	11.848	Ground Surface has Sufficient slope
E4 a	400	-	-	-	-	25	375	14.0	
b	660	660	-	-	-	-	-	3.96	
E5	340	340	-	-	-	-	-	6.0	
E6	450	-	333	117	-	-	-	8.702	
E7	950	-	-	216	333	333	68	14.4	Lift Reqd.
E8&E9	1666	1000	333	333	-	-	-	10	
E10a	300	-	-	-	300	-	-	11.8	Ground Syrface
b	610	610	-	-	-	-	-	3.66	has Sufficient
E11	300	300	-	-	-	-	-	5.46	Slope
E12	545	90	333	122	-	-	-	8.732	
E13a	545	-	-	212	333	-	-	12.00	Lift Reqd.
b	212	212	-	-	-	-	-	1.27	
E14	500	500	-	-	-	-	-	4.27	
E15	400	300	100	-	-	-	-	6.60	
E16	1000	-	233	333	333	100	-	12.60	
E17a.	150	-	-	-	-	150	-	13.50	
b.	450	450	-	-	-	-	-	2.70	Ground Surface
E18	545	545	-	-	-	-	-	6.00	has Sufficient Slope
E19a	150	-	150	-	-	-	-	6.90	Lift Reqd.
b	150	150	-	-	-	-	-	0.9	
E20	850	850	-	-	-	-	-	6.00	
E21	600	333	277	-	-	-	-	10.00	Lift Reqd.
E22	115	115	-	-	-	-	-	.70	To Treatment Plant.

[a]6.0 Inch. PVC Pipe at 0.006 ft/ft slope

TABLE C-5

COMPONENTS OF INSTALLATION COSTS: GRAVITY SEWER SYSTEM ASSUMING NO FURTHER DEVELOPMENTS IN RECREATIONAL FACILITIES, WHITE RIVER LAKE[a]

A. Main Line :	
6.0" PVC 40 Sch Pipe 0-6ft depth: 14448 ft @ $3.2/ft :	$46234.
6.0" Pvc 40 Sch Pipe 6-8 ft depth: 4145 ft @ $3.3/ft ;	13679.
6.0" PVC 40 Sch Pipe 8-10 ft depth:3765 ft @ $4.5/ft :	16943.
6.0" PVC 40 Sch Pipe 10-12 ft depth : 3139 ft. @ $5.0/ft :	15695.
6.0" PVC 40 Sch Pipe 12-14 ft depth ; 1755 ft @ $5.5/ft ;	9653.
6.0" PVC 40 Sch Pipe 14-16 ft depth : 361 ft. @ $6.0/ft :	2166.
B. Sub-Main Lines :	
6.0" PVC 40 Sch.Pipe 0-6 ft depth : 2850 ft@ $3.2/ft :	9120.
6.0" PVC 40 Sch Pipe 6-8 ft depth ; 200 ft@ $3.3/ft :	660.
6.0" PVC 40 Sch Pipe 8-10 ft depth: 1200 ft@ $4.5/ft :	5400.
C. Laterals :	
4.0" PVC 40 Sch Pipe 0-6 ft depth: 6000 ft @ $2.8/ft :	16800.
4.0" PVC 40 Sch Pipe 6-8 ft depth: 350 ft @ $2.9/ft :	1015.
4.0" PVC 40 Sch Pipe 8-10 ft depth: 350 ft @ $3.4/ft :	1190.
D. Manholes and Lift Stations :	
40 Manholes @ $220. each.	8800.
For extra feet depth . 20 ft. @ $ 28.0/ft	560.
Lift Stations : 14 Stations @ $9000./ Stations	126000.
Total Installation Cost	$ 272915.

[a]Sources for cost figures :

Mr. Cecil Hawks, Consultant Engineer, Hicks and Raglands, Lubbock, Texas

City of Abilene:"Preliminary Report on Sewer Project Eligible for Grants", The City Of Abilene, Texas, Nov.1972

City of Jayton :"Preliminary Engineering Report:Wastewater Collection and Treatment Facilities."Jayton,Texas

TABLE C-6

COMPONENTS OF INSTALLATION COST: PRESSURE SEWER SYSTEM ASSUMING NO FURTHER DEVELOPMENTS IN RECREATIONAL FACILITIES, WHITE RIVER LAKE, TEXAS[a]

A. Main Line :		
1.25" PVC 40 Sch. Pipe	379 ft @ $1.75/ft :	$ 663.25
1.50" PVC 40 Sch. Pipe	545 ft @ $1.80/ft :	$ 981.00
2.00" PVC 40 Sch. Pipe	2644 ft @ $2.00/ft :	$ 5088.00
2.50" PVC 40 Sch. Pipe	7929 ft @ $2.10/ft :	$16650.00
3.00" PVC 40 Sch. Pipe	18097 ft @ $2.20/ft :	$39813.40
B. Connection to Main Line From Grinder Pumps :		
1.25" PVC 40 Sch. Pipe	6140 ft @ $1.75/ft :	$10745.00
C. Connection From Individual Homes to Grinders :		
4.00" PVC 40 Sch. Pipe	13100 ft @ $2.80/ft :	$36680.00
D. Grinder Pumps :		
69 Grinder Pumps : Simplex Type (1.5 HP- 230 V)	@ $1040/Pump:	$71760.00
Installation Cost For Grinder Pumps including extra cables, alarm light, and panel boards:	@ $ 150/Pump :	$10390.00
E. Other Accesories :		
29 Valve Boxes @ $50/Box	:	$ 1450.00
2 Clean Out Flushing Devices @ $80/Unit	:	$ 160.00
5 Boosting Stations @ $4000/Station Installed		$20000.00
Total Cost	:	$214381.55

[a]Sources for various cost figures: Mr. Cecil Hawkes, Consultant Engineer,Hicks and Raglend, Lubbock,Tex.; City of Abilene,"preliminary Reports on Sewer Project Eligible For Grants", The City of Abilene, Texas,Nov 1972; City of Jayton,"Preliminary Enginee ring Report;Wastewater collection and Treatment Facilities",Jayton, Texas; Hydromatic Inc., "Specifications for Hydromatic Simplex Pumps and Duplex Pumps",Hydromatic Pump Division, Ashland, Ohio.

APPENDIX D

TREATMENT SYSTEM COSTS

TABLE D-1

FIELD CONSTRUCTION AND OPERATION COSTS (R/MGD DESIGN) ESTIMATING EQUATIONS AS DEVELOPED BY LOGAN ET AL.[a]

Cost Component	Treatment Plant	Construction Cost Equation [a]	Operation Cost Equation [a]
Primary Treatment	Primary High Rate Filters	$Y = 49300\ X^{-.104}$	$Z = 2780\ X^{-.119}$
	Std. Rate Filter	$Y = 35100\ X^{-.028}$	$Z = 2760\ X^{-.235}$
	Activated Sludge.	$Y = 29500\ X^{-0.106}$	$Z = 4560\ X^{-.396}$
		$Y = 18300\ X^{-0.031}$	$Z = 2740\ X^{-.300}$
Secondary Treatment	Primary High Rate Filters	———	———
	Std Rate Filters	$Y = 150,000\ X^{-.404}$	$Z = 4730\ X^{-.435}$
	Activated Sludge.	$Y = 142,000\ X^{-.106}$	$Z = 5360\ X^{-.291}$
		$Y = 197,000\ X^{-.208}$	$Z = 9460\ X^{-.293}$
Total Cost Including Chlorination, Pumping and Administration.	Primary High Rate Filters	$Y = 315,000$	$Z = 12,300\ X^{-.127}$
	Std Rate Filters	$Y = 526,000$	$Z = 17,800\ X^{-.288}$
	Actvated Sludge.	$Y = 430,000$	$Z = 18.900\ X^{-.256}$
		$Y = 597,000$	$Z = 24,300\ X^{-.243}$

Source: Logan et. al. (1962)

Y = Construction Cost per design mgd; Z = Annual Operation Cost per design mgd; All Cost are based on ENR Construction Index of 812. January 1960.

TABLE D-2

EQUATION FOR ESTIMATING CONSTRUCTION COST OF VARIOUS TREATMENT PLANTS AS DEVELOPED BY PUBLIC HEALTH SERVICE[a] AND LAMP[b]

Treatment Type	Construction Cost Equation [c]
Primary Treatment [a]	Log Y = 5.70 - .4460 Log X
Stabilization Pond [a]	Log Y = 5.10 - .4257 Log X
Activated Sludge [a]	Log Y = 5.19 - .2296 Log X
Package Plant [b]	Log Z = 2.6189 + 0.6543 Log X^1

[a]Source: Public Health Service (1963)
[b]Source: Lamp (1974)
[c]Y = Construction cost per mgd in 1957-59 dollars; X = design mgd;
Z = Construction cost of Package plant in 1974 dollars,
X^1 = Plant size in hundreds of gallons per day.

APPENDIX E

IRRIGATION SYSTEM COSTS

TABLE E-1

INSTALLATION COST FOR SOLID-SET SPRINKLER, WHITE RIVER LAKE, TEXAS

A. 5 Acres

Assumption: Square shape plot: 466.69 ft. each side

Item	Unit	Cost/Unit ($/Unit)	Total Cost $
2" Submain	675 ft.	1.25	844.00
1.5" Laterals	2475 ft.	.75	1856.00
1.25" Laterals	1238 ft.	.62	768.00
1" Laterals	1237 ft.	.50	618.50
		Total Pipe Cost	4086.50
1b-Station Controller	1	700	700.00
Sprinkler Heads	121	16.45	1990.00
Electric Valves	16	80.00	1280.00
Wires and Connections	(installed)	250.00	250.00
2 HP Pump-Motor & Electric panel	1	500.00	500.00
		Total	8806.50

Cost per Acre: $1761.5

TABLE E-2

INSTALLATION COSTS FOR AUTOMATIC SUBMATIC DRIP IRRIGATION SYSTEM
WHITE RIVER LAKE, TEXAS

A. 5 Acre, 40' x 40' Spacing

Assumption: Square shape plot

Item	Quantity	Cost/Unit ($/unit)	Total Cost $
40 gpm automated backwashing sand filter	1	1500.00	1500.00
Cartridge sand filter system with valves, electric connections	1	1200.00	1200.00
1 HP pump and motor	1	450.00	450.00
Manually cleaned screen type filter system	2	400.00	400.00
40 gpm Proportioner	1	1000.00	1000.00
Flushing system	1	200.00	200.00
Wash water storage	1	500.00	500.00
Other fittings, housing and tensionometers (2)	1	300.00	300.00
		Sub Total	5550.00
40' x 40' dripline installation with fertilizer injector, secondary strainer, valves, etc.	5 acre	180.00	900.00
		Total	6450.00